Coastal Zone Management Program

A LAKE MICHIGAN COASTAL EROSION
AND RELATED LAND USE MANAGEMENT
STUDY FOR THE CITY OF
ST. FRANCIS, WI

1984

COMMUNITY ASSISTANCE
PLANNING REPORT NO. 110

A LAKE MICHIGAN COASTAL EROSION AND RELATED LAND USE MANAGEMENT STUDY FOR THE CITY OF ST. FRANCIS, WISCONSIN

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COMMUNITY ASSISTANCE PLANNING REPORT NUMBER 110

A LAKE MICHIGAN COASTAL EROSION AND RELATED LAND USE MANAGEMENT STUDY FOR THE CITY OF ST. FRANCIS, WISCONSIN

Prepared by the
Southeastern Wisconsin Regional Planning Commission
P. O. Box 769
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August 1984

Inside Region	$2.50
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SEWRPC LETTERHEAD

August 25, 1984

TO: The Honorable Mayor and Members of the City of St. Francis Common Council

Ladies and Gentlemen:

In March 1982, the City of St. Francis requested that the Regional Planning Commission assist the City in the conduct of a Lake Michigan shoreline erosion and related land use management study, the study being funded, in part, by a federal grant made through the Wisconsin Coastal Management Program, and in part by funds provided by the Wisconsin Electric Power Company and the City itself. The study was initiated in August 1983 and completed in August 1984, the work being carried out by the staff of the Regional Planning Commission, in cooperation with the staff of the City of St. Francis and under the guidance of an advisory committee consisting of representatives of the Wisconsin Electric Power Company, the City of St. Francis, and interested and concerned citizens. This report sets forth the findings and recommendations of the study.

The study quantified the extent of shoreline erosion and bluff recession which may be expected to occur over time along the Lake Michigan shoreline of the City of St. Francis in the absence of any additional structural control measures. In this respect, the study indicated that the bluff recession rates within the City of St. Francis range up to almost six feet per year, and average almost three feet per year along the actively eroding shoreline reaches. This bluff recession results in the loss of about 0.3 acre of shoreland area per year. The study evaluated alternative structural shore protection measures; identified shoreline erosion risk distances and associated recommended setback distances for buildings and facilities along shoreline reaches if proper structural shore protection measures are provided, as well as if such measures are not provided; and resulted in a recommended set of regulations which may be incorporated into the existing city zoning and subdivision ordinances to protect proposed new urban development within those shoreland areas susceptible to erosion and bluff recession.

The Regional Planning Commission is pleased to have been able to be of assistance to the City in the completion of this study. The Commission stands ready, upon request, to assist the City in presenting the information and recommendations contained in this report to the public for its review and evaluation, and in adopting and implementing the recommendations contained in this report.

Sincerely,

Kurt W. Bauer

Kurt W. Bauer
Executive Director

ST. FRANCIS

76% ORIG. SIZE

Chapter I

INTRODUCTION

In March 1982, the City of St. Francis requested that the Regional Planning Commission assist the City in seeking solutions to the severe erosion problems occurring along the Lake Michigan shoreline bordering the site of the Wisconsin Electric Power Company's (WEPCo's) Lakeside electric power generating facility. That facility, moreover, ceased operation on October 1, 1983, presenting the City with a need to consider alternative means of solving the erosion problem and to develop related land use regulations. Subsequently, the Commission applied for, and obtained on behalf of the City, a grant under the Wisconsin Coastal Management Program in partial support of a coastal erosion and related land use management study for the WEPCo Lakeside property, as well as for the remaining Lake Michigan coastal area within the City of St. Francis. The study was carried out cooperatively by the staffs of the City and the Regional Planning Commission under the guidance of an advisory committee created by the City of St. Francis. The committee consisted of representatives of the Wisconsin Electric Power Company, City of St. Francis, Milwaukee County Park Commission, Wisconsin Department of Natural Resources, and interested and concerned citizens. The functions of the Committee were to articulate the purpose and define the scope and content of the study, as well as to develop a recommended shoreline erosion control and related land use management plan for the Lake Michigan shoreline through the City of St. Francis. The study includes an inventory and analysis of the existing shoreline erosion and bluff recession conditions, and provides recommendations for erosion control and related land use management in the study area.

DEFINITION OF COASTAL EROSION AND RELATED LAND USE MANAGEMENT

For the purposes of this study, coastal erosion management is defined as a coordinated set of measures designed to abate coastal erosion and reduce attendant property losses, aesthetic impacts, and risks to human safety which result from such erosion. Erosion management measures include both structural measures--such as the construction of revetments and bulkheads--and nonstructural measures--such as land use regulations which prohibit certain types of development in erosion-prone shoreland areas. The broad goal of coastal erosion management is the preservation of the overall quality of life of the residents of an area through the selective protection of high-value physical resources and those environmental values--recreational, aesthetic, ecological, and cultural--normally associated with and concentrated in coastal areas.

NEED FOR A COASTAL EROSION AND RELATED LAND USE MANAGEMENT STUDY

The erosion, and subsequent recession, of coastal bluffs constitutes one of the most adverse impacts of coastal erosion processes. Bluff recession rates in the City of St. Francis study area range up to five feet per year, resulting in the loss of approximately 25,000 square feet of land each year, and approximately 1.4 million cubic feet of shore material from the study area. This severe erosion is concentrated within a narrow strip of shoreline.

Because the entire Lake Michigan shoreline within the City of St. Francis is owned by the Wisconsin Electric Power Company and by Milwaukee County, there has been no need for the City to incorporate specific shoreline setback distance requirements into its existing zoning ordinance or other shoreland regulations. The zoning ordinance specifies a minimum rear yard depth of 25 feet. The city land subdivision control ordinance requires a minimum total lot depth of 100 feet. There is no county shoreline zoning ordinance that applies within the City of St. Francis.

The significant data base set forth in this study provides an opportunity to refine the city zoning and land subdivision control ordinances by establishing development setbacks and other use restrictions related to shoreline and bluff recession rates, as well as to stable bluff slope configuration. Because the City's coastal area represents an extremely valuable resource, and because the competition for coastal resources is increasing, setback distances and other regulations are developed in this study, and structural shore protection measures and suitable land uses are evaluated.

COASTAL EROSION AND RELATED LAND USE MANAGEMENT STUDY AREA

The City of St. Francis coastal erosion and land use management study area consists of the existing 130-acre Lakeside property owned by the Wisconsin Electric Power Company, and the remaining 32-acre Lake Michigan shoreline area within the City of St. Francis, as shown on Map 1. The total study area has an areal extent of about 162 acres, and consists of all that portion of the City of St. Francis which most directly affects, and is most affected by, Lake Michigan resources and processes. The triangular land parcel within the study area located west of South Lake Drive is expected to continue to be used as a substation by the Wisconsin Electric Power Company. The land parcel is not expected to affect, or be affected by, shore protection measures.

While this study focuses on a relatively narrow strip of land along the Lake Michigan shoreline, it must be recognized that the study area is set within the broader framework of a comprehensive local development plan. Accordingly, the study recognizes, for example, the extent of existing sanitary sewerage and public water supply service areas affecting the study area. In addition, it is recognized that the Lake Michigan coastal area provides unique recreational opportunities which attract users from well inland. Due consideration is given in the study to these and other important linkages between the study area and the balance of the City, the County, and the Southeastern Wisconsin Region.

PURPOSE AND SCOPE

The primary purpose of the City of St. Francis coastal erosion and related land use management study is to delineate high erosion risk areas along the Lake Michigan shoreline, to recommend measures for erosion control, and to determine suitable related regulations for the study area. To accomplish this purpose, the following specific work elements were undertaken as part of the coastal erosion management and land use study:

1. The collation of all pertinent data relating to shoreline erosion and bluff recession in the study area and to the characteristics of the natural resource base which affect land use development.

Map 1

CITY OF ST. FRANCIS COASTAL EROSION AND RELATED LAND USE MANAGEMENT STUDY AREA

N-ARROW

Source: SEWRPC.

2. The preparation of large-scale, one inch equals 100 feet topographic maps of the shoreline area of the City of St. Francis, together with attendant horizontal and vertical survey control, which can be used to evaluate existing conditions and to develop alternative coastal erosion management measures and land uses.

3. The identification and mapping of high erosion risk areas and the determination of coastal recession rates, stable bluff slope angles, and areas of impact.

4. The development and evaluation of alternative coastal erosion management measures and related land uses and land use regulations based upon the inventory and erosion hazard data.

5. The recommendation of nonstructural and structural erosion control measures, the development of recommended land uses and land use regulations for the study area, and the determination of the means of implementing these recommendations.

Control of coastal erosion in the City of St. Francis requires an integrated approach involving both structural and nonstructural measures. The degree of erosion and the effectiveness of erosion abatement measures are highly site-specific and may vary over time. Factors such as Lake Michigan water elevations, upcurrent erosion control measures, and changing wind and wave characteristics contribute to and complicate this variability. Therefore, structural erosion control measures, as well as a continuing program of data collection, will be needed in addition to nonstructural measures for an effective erosion control program.

The Lake Michigan coastal area of the City of St. Francis provides a potentially attractive setting for various land uses competing for the limited natural resource amenities. The purpose of this study is to evaluate the impacts of these alternative land uses on the natural resource base--particularly on shoreline erosion and bluff recession--and to define which land uses and land use regulations would be appropriate for the WEPCo Lakeside property and remaining coastal areas within the City of St. Francis. The recommended land uses should minimize shoreline erosion damages and not have an adverse effect on the bluff recession rates or processes. The results of this study represent an important step toward the development of a coastal erosion management plan for the City of St. Francis.

SUMMARY

In March 1982, the City of St. Francis requested that the Regional Planning Commission assist the City in seeking solutions to the severe erosion problems occurring along the Lake Michigan shoreline bordering the site of the Wisconsin Electric Power Company's Lakeside electric power generating facility. That facility, moreover, ceased operation on October 1, 1983, presenting the City with a need to consider potential alternative means of solving the erosion problem and to develop related land use reguations. Subsequently, with financial assistance from the Wisconsin Coastal Management Program, a coastal erosion and related land use management study of the Lakeside site and of the remaining coastal area within the City of St. Francis was undertaken cooperatively by the City and Commission staffs working under the guidance of an advisory committee created by the City.

The primary purpose of this study was to identify and map high erosion risk areas along the Lake Michigan shoreline, to recommend measures for management of this coastal erosion, and to recommend appropriate land uses and land use regulations for the study area which are properly related to the shoreland and bluff recession rates and which appropriately utilize the shoreland resources.

Coastal erosion management is defined for the purposes of this study as the coordination of structural and nonstructural shore protection measures designed to abate shoreline erosion and reduce damages which result from such erosion. Currently, there are no city, county, or state shoreland zoning or other land use regulations governing shoreland development in the City of St. Francis. Because of the extremely valuable resources contained within the shoreland area and the increasing demand for these coastal resources, there is a need to establish development setbacks and other use restrictions which are related to bluff recession rates and stable slope configurations, and to define needed structural control measures.

Proposing land uses suitable for the coastal area requires consideration of many interrelated factors. Land uses appropriate for the Lakeside property and remaining coastal areas within the City of St. Francis should signifi-

cantly benefit from, or be enhanced by, the shoreland area, minimize shoreline erosion damages, and not have an adverse effect on the bluff recession rates or processes.

Work elements undertaken as part of this study include the collection of coastal erosion data, the preparation of large-scale topographic maps, the delineation and mapping of high erosion risk areas based on existing and historical coastal recession rates, the evaluation of alternative erosion management measures and appropriate land uses, and the recommendation of coastal erosion management measures and related land use regulations for the study area.

Chapter II

INVENTORY FINDINGS

INTRODUCTION

In order to identify and evaluate alternative structural and nonstructural shoreland protection measures, high-risk erosion areas must be delineated, and careful consideration must be given to the existing land use pattern, the natural resource base of the shoreland area, and coastal erosion processes and rates and existing structural protection measures. Accordingly, this chapter describes the Lake Michigan shoreland study area, and provides pertinent information on the elements of the natural resource base relevant to coastal erosion and related land use management, a summary of existing land use and zoning patterns, and a detailed analysis and inventory of the types, causes, and rates of shoreline erosion and bluff recession occuring within the City of St. Francis.

The study area, as defined in Chapter I and shown on Map 1, generally includes that portion of the City of St. Francis which most directly affects, and is most affected by, Lake Michigan resources and processes. Certain of the data presented herein, including data on soils, bluff characteristics, and types and causes of bluff erosion, were collected by special surveys conducted under the study by the U. S. Department of Agriculture, Soil Conservation Service and the University of Wisconsin working in cooperation with the Regional Planning Commission. Other inventory data--such as data on the geology, groundwater resources, and climate of the area--were collated from existing sources. Some of the inventory data, such as data on existing zoning, land use, and soils, are presented for the entire study area. Other inventory data, particularly data on coastal erosion processes, rates, and problems and existing structural shore protection measures, are presented only for the immediate shoreland area. As appropriate, other data, such as data on climatic, geologic, and groundwater conditions, are presented for adjacent inland portions of the City of St. Francis area as well as for the shoreland area.

This chapter consists of seven sections. The first section describes the natural resource base pertinent to coastal erosion management. The second section discusses the existing land use pattern of the study area, and provides information on the comprehensive zoning district boundaries and related regulations within the study area. The third section describes coastal erosion processes. The fourth section concerns special-purpose shoreland development regulations. Structural shore protection measures are described in the fifth section, and the sixth section identifies the coastal erosion problems of the area. The seventh and final section presents data on historical bluff recession.

NATURAL RESOURCE BASE

This section describes those aspects of the natural resource base which affect, or may be affected by, coastal erosion management. Data are presented on the bedrock geology and glacial deposits, soils, beach and bluff characteristics, groundwater resources, and climate of the shoreland and related areas.

Bedrock Geology and Glacial Deposits

The consolidated bedrock underlying Milwaukee County generally dips eastward at a rate of 25 to 30 feet per mile. Precambrian-age crystalline rock formations form the basement of the bedrock and are thousands of feet thick. Cambrian sandstone rock formations imbedded with siltstone and shale lie above the crystalline rock formations and are more than 800 feet thick. Above the Cambrian rock formations lie Ordovician sandstone, dolomite, and shale formations whose thickness approximates 700 feet. The bedrock closest to the surface is composed of Silurian dolomite, primarily Niagara dolomite, which is approximately 300 feet thick in the St. Francis study area. The Silurian Formations are covered by glacial deposits ranging up to 100 feet in thickness within the study area.

Materials directly deposited by glacial ice are called till. The St. Francis study area is overlain by till believed to have been deposited by ice of the Lake Michigan lobe during the Wisconsin stage of glaciation. Several layers of glacial debris can be identified in the study area. The surface layer, which ranges up to 115 feet in thickness, is known as the Oak Creek Formation.[1] This formation is composed of a pebbly, silty clay loam till; lacustrine clay, silt, and sand; and glaciofluvial sand and gravel. This formation is believed to have been deposited between 12,500 and 14,000 years ago, when the Lake Michigan lobe moved southwestward out of the current Lake Michigan basin. During brief periods of glacial recession, lacustrine sediment was deposited. Directly beneath the Oak Creek Formation lies a layer known as the New Berlin Formation which ranges in thickness up to 70 feet and consists of a lower sand and gravel member and an upper till member. The New Berlin till is a coarser-grained till, sandy in texture and dominated by pebbles, cobbles, and even some boulders. The gravel member is believed to have been deposited between 14,000 and 16,000 years ago as an outwash plain in front of and around the advancing Delavan sublobe of the Lake Michigan lobe. Continued advance of the glacier deposited the till members. The Zenda Formation, whose maximum thickness is unknown at this time, lies beneath the New Berlin Formation. The upper layer of the Zenda Formation is known as the Tiskilwa member. The till of the Tiskilwa member is described as medium textured, much finer than the New Berlin till. The Zenda Formation is believed to have been deposited by the Harvard sublobe of the Lake Michigan lobe between 18,000 and 20,000 years ago.

All three glacial formations are exposed by the bluffs within the study area. Within the exposed bluffs, the Oak Creek Formation ranges from 40 to 60 feet thick, the New Berlin Formation ranges up to 10 feet thick, and the Zenda Formation ranges up to 5 feet thick. The properties of these glacial deposits influence the resistance of the bluffs to processes such as wave erosion, and ultimately affect the severity and rate of bluff recession. Additional glacial deposits are located beneath the lake level, but do not affect shoreline erosion or bluff recession.

Soils

Soil properties influence the severity of bluff erosion as well as the manner in which the land can be used. Certain soil properties, such as infiltration

[1]D. M. Mickelson et. al., "Pleistocene Stratigraphic Units of Wisconsin," Wisconsin Geological and Natural History Survey, unpublished.

Map 2

SOILS WITHIN THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELAND STUDY AREA

Source: SEWRPC.

capacity and permeability, will affect the degree of surface erosion which occurs. Soil properties also are an important consideration in the evaluation of groundwater seepage from the bluff face. In the evaluation of suitable land uses for the study area, important soil properties include shear strength, compressibility, permeability, shrink-swell characteristics, depth to water table, slope, and bearing capacity.

A special survey of the soils within the study area was conducted by the U. S. Department of Agriculture, Soil Conservation Service for the Regional Planning Commission in November 1983. The results of the survey indicated that the soils in the study area are a combination of the Ozaukee Series classification and of disturbed soils. Map 2 shows the spatial distribution of soils within the study area. The disturbed soils, which primarily include fill areas, cover about 71 acres, or 44 percent of the study area, and in general cover the fenced-in portion of the Wisconsin Electric Power Company power plant site east of Lake Drive and the area immediately west of Lake Drive in the area of the power plant site. The soils natural to this area have been disrupted too extensively by human activity to allow an evaluation of the properties except by borings and tests.

The Ozaukee soils cover 86 acres, or 53 percent of the study area. This soil type commonly develops on calcareous silty clay loams on glacial uplands. A large amount of surface stormwater runoff can be generated from Ozaukee soils because of their low infiltration capacity, low permeability, and poor drainage. The soil may therefore contribute substantial surface runoff over the top of the bluffs, causing surface erosion of the bluff face. The soil's low bearing capacity and high shrink-swell potential limits the type of structures which can be built in some portions of the study area without special design and construction measures. The remaining five acres, or 3 percent of the study area, are covered by water and are enclosed by the power company dike.

Bluff Characteristics

The bluffs along the City of St. Francis shoreline of Lake Michigan exhibit a variety of height, slope, composition, vegetative cover, and structural protection conditions. These conditions affect the degree and rate of bluff recession along different segments of the study area. This section describes the physical characteristics--the height and composition--of the bluffs, as surveyed in December 1983. Bluff erosion processes, structural protection measures, slope stability analyses, and bluff recession rates are described in later sections of this chapter.

Table 1 summarizes the length of shoreline within various bluff height ranges. Bluff heights are also shown in Figure 1. In the southernmost portion of the study area bluffs reach their maximum height of nearly 70 feet above lake level. Northward to the Wisconsin Electric Power Company power plant site, the bluffs generally range in height from 40 to 60 feet above the lake level. North of the power plant the bluffs generally range in height from 40 to 50 feet above lake level; decreasing at the southern end of Bay View Park to about 30 feet in height. Near the northernmost portion of the study area the bluff heights again rise to more than 40 feet. About 28 percent of the shoreline has bluffs equal to or less than 40 feet in height above lake level. About 47 percent of the shoreline has bluffs ranging from 41 through 50 feet in height, and nearly 20 percent of the shoreline has bluffs ranging from over 50 to 60 feet in height. Less than 5 percent of the shoreline has bluffs higher than 60 feet.

The City of St. Francis shoreline bluffs are composed of a variety of materials. Table 2 indicates the predominant types of materials along the shoreline, and Figure 1 shows by longitudinal section the composition of the bluffs. About 54 percent of the bluffs were well vegetated and protected in 1983 and not actively eroding. The predominant materials within these stable areas were not determined. Along the unstable areas, Oak Creek till was found to be the predominant bluff material, prevailing along approximately 30 percent of the total shoreline, and along 65 percent of the total actively eroding shoreline. Sand and gravel were found to be the second most common bluff materials, predominating along about 11 percent of the total shoreline, and along 24 percent of the total actively eroding shoreline. Silt and sand were identified as the predominant bluff material along approximately 5 percent of the total shoreline and along 11 percent of the total actively eroding shoreline. New Berlin till, Tiskilwa till, silt and clay, and sand were also identified in the bluffs, but were never found to be predominant materials.

Table 1

SUMMARY OF BLUFF HEIGHTS ALONG THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS DECEMBER 1983

Bluff Height (feet)	Length of Shoreline (feet)	Percent of Total Study Area Shoreline Length
0-30	240	2.5
31-40	2,500	26.0
41-50	4,520	47.0
51-60	1,920	20.0
61-70	440	4.5
Total	9,620	100.0

Source: SEWRPC.

Figure 1

LONGITUDINAL SECTION THROUGH THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS SHOWING BLUFF HEIGHT AND COMPOSITION: 1983

Source: D. M. Mickelson and SEWRPC.

Table 2

BLUFF COMPOSITION ALONG THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS: 1983

Predominant Material	Other Material Present	Shoreline Length (feet)	Percent of Total Shoreline Length	Percent of Total Actively Eroding Shoreline Length
Oak Creek Till	Sand	900	9.4	20.3
	Silt and Sand Sand and Gravel	650	6.7	14.6
	Sand Sand and Gravel	450	4.7	10.1
	Silt and Clay Silt and Sand Sand and Gravel	290	3.0	6.5
	Sand and Gravel	250	2.6	5.6
	Silt and Sand Sand and Gravel New Berlin Till	200	2.1	4.5
	Sand and Gravel New Berlin Till Tiskilwa Till	150	1.6	3.4
Subtotal	--	2,890	30.1	65.0
Sand and Gravel	Oak Creek Till New Berlin Till Tiskilwa Till	300	3.1	6.8
	New Berlin Till Silt and Sand	300	3.1	6.8
	Oak Creek Till New Berlin Till	250	2.6	5.6
	Silt and Sand	200	2.1	4.5
Subtotal	--	1,050	10.9	23.7
Silt and Sand	Oak Creek Till New Berlin Till Sand and Gravel	350	3.6	7.9
	Sand and Gravel New Berlin Till	150	1.6	3.4
Subtotal	--	500	5.2	11.3
Undetermined, Vegetated	--	5,180	53.8	--
Total	--	9,620	100.0	100.0

Source: SEWRPC.

Beach Characteristics

A beach may be defined as an area of unconsolidated material which extends landward from the ordinary low-water line to the line marking a distinct change in physiographic form, or the beginning of permanent terrestrial vegetation. The width of a beach and the size and character of the sediments found on beaches vary widely in response to the lake water level, the degree of wave action affecting the beach, the slope of the beach face and the near-shore lake bottom, the kinds of material available near the shore for the formation of beaches, and man-made structures. The beach widths were measured in December 1983, when the lake water level was relatively low. Beach widths were also observed during July 1984, when the lake water level was higher, and the beaches were considerably narrower than in the December survey.

The beaches in the City of St. Francis are composed primarily of sand, gravel, cobbles, and boulders; small particles like silt and clay do not usually remain on the beach as do the large-size materials, since clay and silt are more readily kept in suspension and carried out into the lake. These finer materials tend to ultimately settle out in calmer, deeper, off-shore waters.

South of the Wisconsin Electric Power Company power plant site, the beach is composed primarily of sand, gravel, and cobbles. Large boulders are also scattered in areas where the New Berlin till is exposed at the base of the bluff. Figure 1 shows these areas. The width of the beach along this portion of the shoreline in December 1983 ranges from 10 to 30 feet. Sand and gravel are predominant along the beach north of the power plant site. The beach in this area is generally wider than south of the plant site, ranging from 10 feet wide to greater than 100 feet wide in December. The southern extent of the Milwaukee South Shore breakwater lessens the impact of wave action on this shoreline, allowing wider beaches to develop.

Summary data on beach widths surveyed in December 1983 in the City of St. Francis are provided in Table 3. The shoreline along the Wisconsin Electric Power Company power plant site, which accounts for approximately 31 percent of the study area shoreline, contains no beach, with the lake reaching the shore protection structures that surround the plant site. About 28 percent of the shoreline had a beach ranging from 1 foot through 20 feet wide. About 17 percent of the shoreline had a beach ranging from 21 feet through 40 feet wide, and about 9 percent had a beach ranging from 41 feet through 60 feet wide. About 15 percent of the shoreline, located in the far northern portion of the study area, had a beach over 60 feet wide. The wider beaches tend to have flatter slopes and are composed of finer-grained materials,

Table 3

SUMMARY OF BEACH WIDTHS ALONG THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS

Beach Width (feet)	Length of Shoreline (feet)	Percent of Study Area Shoreline Length
0	2,940	30.6
1-20	2,700	28.1
21-40	1,620	16.8
41-60	880	9.1
60	1,480	15.4
Total	9,620	100.0

Source: SEWRPC.

whereas the narrower beaches tend to have steeper slopes and are composed of coarser-grained materials.

Groundwater Resources

The occurrence, distribution, direction, and quantity of flow of groundwater have important impacts on the stability of bluff slopes. Along the City of St. Francis shoreline, groundwater generally flows toward the lake and discharges either at, or below, the base of the bluff into the lake, or seeps out of the bluff face at some elevation above lake level. The presence of groundwater in the bluff reduces the frictional resistance to stress, creates a seepage pressure in the direction of water flow, adds weight to the bluff, and causes undercutting of bluff materials.

There are two major aquifers beneath the St. Francis study area. These aquifers are commonly called the deep sandstone aquifer and the shallow Niagara dolomite aquifer. The aquifers differ widely in water yield capabilities and extend to great depths.

The deep sandstone aquifer, which is known to be more than 1,300 feet thick, underlies the entire County and is composed of Cambrian- and Ordovician-age strata. The top of this aquifer lies about 600 feet below the surface of the study area. Most recharge of the sandstone aquifer is by lateral movement of water down the hydraulic gradient from west of the study area.

The shallow dolomite aquifer, referred to as the Niagara aquifer, is composed of Silurian-age strata, and is about 300 feet thick. The top of this aquifer lies up to 100 feet below the surface of the study area. Recharge of this aquifer is by the downward seepage of precipitation which falls in the immediate area. Some recharge may also be induced from Lake Michigan; however, if this does occur, the relatively impermeable layers of lake silt and glacial drift make it a very slow process.

Above the Niagara dolomite is a layer of unconsolidated glacial deposits composed primarily of till and sand and gravel. These deposits range in thickness up to 100 feet over the study area. The sand and gravel layers may act as water-bearing units. Seepage from the bluff slopes is primarily contained within these sand and gravel layers.

Climate

Air temperature and the type, intensity, and duration of precipitation events affect the degree and extent of shoreline erosion. Climate impacts on shoreline erosion include freeze-thaw actions caused by water contained within the bluff material, high surface runoff from frozen soils in early spring, the reduction of wave action due to ice formation on the lake, high levels of surface runoff, and soil erosion following periods of heavy rainfall.

Air temperature impacts primarily include the formation of ice on the lake, the initiation of freeze-thaw actions on soils, and high runoff rates from frozen soils. Table 4 presents average monthly air temperature variations at the Milwaukee National Weather Service Station for the 30-year period from 1951 through 1980. The 30-year period of meteorological record of 1951 through 1980 corresponds to the World Meteorological Organization's normal climatic

Table 4

AVERAGE MONTHLY AIR TEMPERATURE AT MILWAUKEE 1951 THROUGH 1980

Month	Average Daily Maximum	Average Daily Minimum	Mean
January....	26.0	11.3	18.7
February...	30.1	15.8	23.0
March......	39.2	24.9	32.1
April......	53.5	35.6	44.6
May........	64.8	44.7	54.8
June.......	75.0	54.7	64.9
July.......	79.8	61.1	70.5
August.....	78.4	60.2	69.3
September..	71.2	52.5	61.9
October....	59.9	41.9	50.9
November...	44.7	29.9	37.3
December...	32.0	18.2	25.1
Annual	54.6	37.6	46.1

Source: National Weather Service and SEWRPC.

Table 5

AVERAGE MONTHLY PRECIPITATION AND SNOW AND SLEET AT MILWAUKEE: 1951 THROUGH 1980

Month	Average Total Precipitation (inches)	Average Snow and Sleet (inches)
January....	1.64	13.5
February...	1.33	10.5
March......	2.58	10.1
April......	3.37	2.1
May........	2.66	Trace
June.......	3.59	0.0
July.......	3.54	0.0
August.....	3.09	0.0
September..	2.88	Trace
October....	2.25	0.2
November...	1.98	3.4
December...	2.03	11.4
Year	30.94	51.2

Source: National Weather Service and SEWRPC.

period. As shown in the table, winter temperatures, as measured by the monthly means for December, January, and February, range from 18.7° to 25.1° F. Summer temperatures, as measured by the monthly means for June, July, and August, average from 64.9° to 70.5° F.

The depth and duration of ground frost, or frozen ground, influences hydrologic and soil erosion processes, particularly freeze-thaw activity and the proportion of total rainfall or snowmelt that will run off the land. The amount of snow cover is an important determinant of frost depth. Since the thermal conductivity of snow cover is less than one-fifth that of moist soil, heat loss from the soil to the colder atmosphere is greatly inhibited by the insulating snow cover. Snow cover is most likely during the months of December, January, and February, during which there is at least a 40 percent probability of having one inch or more of snow cover, as measured at the Milwaukee weather station. Frozen ground is likely to exist throughout the study area for approximately four months each winter season, extending from late November through early March, with more than six inches of frost occurring in January, February, and the first half of March. Near-shore portions of Lake Michigan may begin to freeze in December, and ice breakup normally occurs in late March or early April.

Precipitation within the study area takes the form of rain, sleet, hail, and snow, and ranges from gentle showers of trace quantities to brief but intense and potentially destructive thunderstorms or major rainfall-snowmelt events causing severe bluff and beach erosion. Average monthly and annual total precipitation and snowfall for the Milwaukee National Weather Service Station are presented in Table 5. The average annual total precipitation in the Milwaukee area was 30.94 inches over the 30-year period from 1951 through 1980. Average total monthly precipitation for the Milwaukee area ranges from 1.33 inches in February to 3.59 inches in June. The average annual snowfall and sleet, measured as snow and sleet, over the 30-year period from 1951 through 1980 was 51.2 inches. Assuming that 10 inches of measured snowfall and sleet are equivalent to one inch of water, the average annual snowfall of 51.2 inches is equivalent to 5.12 inches of water. Therefore, only about 17 percent of the average annual total precipitation occurs as snowfall and sleet. The principal snowfall months are December, January, February, and March, during which 89 percent of the average annual snowfall may be expected to occur.

Extreme precipitation events may result in massive shoreline losses due to high levels of erosion, seepage, and slumping, A one-hour storm with an expected average recurrence interval of once every two years may be expected to have a total rainfall of about 1.2 inches.[2] A one-hour, 10-year recurrence interval storm may be expected to have a total rainfall of about 1.8 inches, and a 24-hour, 10-year recurrence interval storm may be expected to have a total rainfall of about 3.7 inches. Extended wet periods may also result in unusually high coastal losses. Over the period from 1841 through 1980, the maximum annual amount of precipitation at Milwaukee was 50.36 inches in 1876, or 63 percent above the 1951 through 1980 annual average.[3] The maximum monthly precipitation amount was 10.83 inches, which occurred in June 1917.

The presence of Lake Michigan tends to moderate the climate of the City of St. Francis. This is particularly true during those periods when the temperature differential between the lake water and the land air masses is the greatest. It is common, for example, for mid-day summer temperatures to be 10°F lower in shoreline areas than in inland areas because of the cooling lake breezes. Lake Michigan does not have as pronounced an effect on precipitation as it does on temperature. A minor Lake Michigan effect is apparent in the late spring and summer, when there is about 0.5 inch less rainfall per month in coastal areas than in areas farther inland. This difference may be attributed to the cool lake waters maintaining a cooler lower atmosphere which inhibits convective precipitation. However, during the winter, Lake Michigan can serve as a source of moisture, resulting in slightly higher snowfalls near the lake.

MAN-MADE FEATURES

An understanding of the existing land use patterns and zoning regulations is essential to the sound formation of practical development guidelines for the coastal area experiencing bluff recession in the study area. Knowledge of these factors, along with the consideration of existing facilities and structures in the Wisconsin Electric Power Company power plant site, will also aid in the determination of which land uses and land use regulations would be appropriate for the power plant site and remaining coastal areas of the City of St. Francis. Accordingly, this section describes the existing land use and zoning within the study area and the facilities and structures on the power plant property.

Existing Land Use

The type and spatial distribution of the land uses existing within the St. Francis coastal erosion study area in 1980 are summarized on Map 3. The

[2]Kurt W. Bauer, "Determination of Runoff for Urban Storm Water Drainage System Design," SEWRPC Technical Record, Volume Two, No. 4, April-May 1965.

[3]National Weather Service, Wisconsin Statistical Reporting Service, and SEWRPC.

areal extent of the land use categories within the study area, which encompasses a total of 161.5 acres, is presented in Table 6. The largest single land use category was unused urban land, which occupied a total of 69.9 acres, or about 43 percent of the study area. Unused urban land areas are, by definition, lacking any intensive urban use or any identifiable natural resource base element such as a woodland, wetland, or water area. The communication and utilities land use category, which includes the Wisconsin Electric Power Company power plant site, covers about 49.8 acres, or 31 percent of the study area. The study area also contains approximately 30 acres of parkland which comprises about 14 percent of the study area. This land is utilized for both land-based and water-based recreational activities.

Table 6

EXISTING LAND USE IN THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELANE STUDY AREA: 1980

Land Use Category	Area (acres)	Percent of Total
Communication and Utilities......	49.8	30.8
Parks...............	22.9	14.2
Off-Street Parking..	2.0	1.2
Street..............	11.5	7.1
Unused Urban Land...	69.9	43.3
Water...............	5.4	3.4
Total	161.5	100.0

Source: SEWRPC.

Existing Zoning

Zoning ordinances and attendant zoning district maps provide an important expression of community land use development objectives. The existing City of St. Francis zoning ordinance divides the study area into three zoning districts, as shown on Map 4. All the zoning districts within the study area permit urban development.

The largest zoning category is industrial, which accounts for 73 acres, or 45 percent of the study area. The industrial district is applied solely to the Wisconsin Electric Power Company power plant site and accounts for about 3,300 feet, or 36 percent, of the Lake Michigan shoreline in the City of St. Francis. The zoning district south of the power plant, comprising an additional 57 acres, or 36 percent of the study area, is residential. This district accounts for 3,100 feet, or 32 percent of the shoreline. An institutional zoning district lies north of the power plant site and accounts for the balance of 32 acres, or 20 percent of the study area. This zoning district contains the remaining 3,300 feet, or 34 percent, of Lake Michigan shoreline in the City of St. Francis.

Existing Facilities and Buildings

The Wisconsin Electric Power Company currently owns approximately 80 percent of the land in the study area. The power company property, as shown on Map 5, includes all land from the southernmost boundary of the study area, where it borders Sheridan Park, to Bay View Park, with a total areal extent of 130 acres. The power company property accounts for about 6,200 feet, or 64 percent, of the Lake Michigan shoreline in the study area. The power company main plant site is defined as the fenced-in portion of the property shown in Map 6. In addition, the Wisconsin Electric Power Company owns a 15-acre vacant

Map 3

EXISTING LAND USE WITHIN
THE CITY OF ST. FRANCIS
LAKE MICHIGAN SHORELAND
STUDY AREA: 1980

Source: SEWRPC.

Map 4

EXISTING ZONING DISTRICTS
FOR THE CITY OF ST. FRANCIS
LAKE MICHIGAN SHORELAND
STUDY AREA: 1983

Source: SEWRPC.

parcel of land north of the main plant site and a 39-acre vacant parcel of land south of the main plant site. These vacant areas account for 42 percent of the property.

The construction of the Lakeside power plant was initiated in 1920 and completed in 1930. The plant ceased primary operation in October 1983. The main plant facility, consisting of a turbine room, three boiler rooms, a switch house, and an office area, is approximately 450 feet long by 300 feet wide by 90 feet high.

Located directly east of the main plant are three chimneys standing 240 feet high and having a base diameter of 24 feet. Adjacent to the chimneys are three

Map 5

LOCATION OF THE WISCONSIN ELECTRIC POWER COMPANY PROPERTY WITHIN THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELAND STUDY AREA

Source: SEWRPC.

Map 6

WISCONSIN ELECTRIC POWER COMPANY FACILITIES AND BUILDINGS

Source: SEWRPC.

"aerotec" buildings used for storage, and two turbine generators, associated switches, and control equipment. A gate house is located adjacent to the northwest side of the building. In a yard area north of the plant are three fuel oil storage tanks and a storage shed. A switchyard comprised of three step-up transformers is located south of the main plant building. West of Lake Drive lie 21 acres of Wisconsin Electric Power Company property. Included in this area is an employee parking lot and a substation and switchyard area. Extending the full length of the power company property and running along the east side of Lake Drive is a bike path leased to Milwaukee County. Located in the near-shore area of Lake Michigan are a settling basin, an intake pond, and water intake and discharge facilities. The settling basin was used for the temporary storage of washwater and floor drain discharges from the main power plant building prior to its discharge back to the intake pond. The intake pond is enclosed by a dike. Intake facilities consist of steel stop gates, concrete intake structures, and underground tunnels which conveyed water from the intake pond to the main power plant building. When the plant was in operation, condenser cooling water from the main plant building was discharged at five outfall sites; three outfalls discharged to the intake pond and two outfalls discharged directly to Lake Michigan immediately north and south of the dike. The discharge facilities consist of discharge gates and underground tunnels which conveyed cooling water from the main power plant building to the outfall sites.

Sanitary wastewater from the Wisconsin Electric Power Company facilities is conveyed to, and treated by, the Milwaukee Metropolitan Sewerage District's Jones Island wastewater treatment plant. A sanitary sewer borders the western boundary of the study area. A water main is located along the entire length of S. Lake Drive within the study area.

COASTAL EROSION PROCESSES

Erosion of the Lake Michigan shoreline is a natural process which can be accelerated--such as by increasing the rate and volume of stormwater runoff--or decelerated--such as by the construction of shore protection measures--by human activities. Shoreline erosion includes two processes, bluff erosion and beach erosion, but bluff erosion is of particular concern because it poses a threat to property and human safety. Various factors contribute to bluff erosion and beach erosion, including wave action, groundwater seepage, precipitation runoff, lake level elevation, freeze-thaw action, lake ice movement, and the type of vegetative cover.

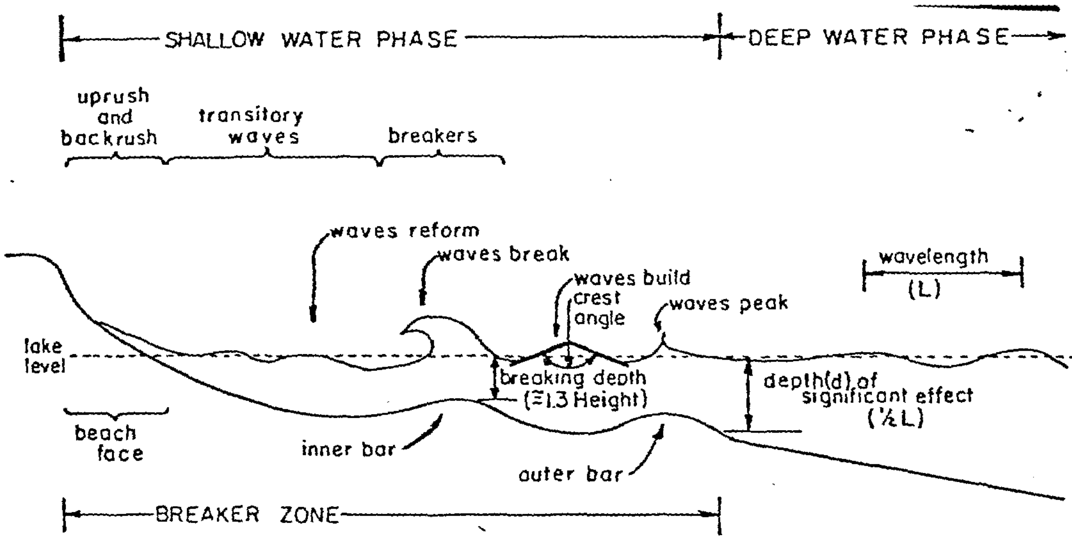
Bluff Erosion

Bluff erosion occurs in the form of toe erosion, slumping, sliding, flow, surface erosion, and solifluction, and results in the intermittent, sometimes massive, recession of the bluff. On all slopes gravity acts to move material on the slope to a lower elevation. On most slopes which are undisturbed by man, and where waves are not eroding the base of the slope, an equilibrium is established over a relatively long period of time between the forces acting to move material down the slope and the resistance of the materials in the slope to those forces. The shear stress of the materials in the bluffs is primarily determined by the weight of the soil and water mass in the bluff, water pressures in the bluff, external loads such as buildings, vibrations, and the degree of lateral support from the bluff slope. Bluff materials have a shear strength which is normally greater than these stresses. The shear strength depends on the properties of the soil, the loading on the soil, and the moisture content, which is in part determined by soil drainage. Bluffs fail when either the shear stress is increased or the shear strength decreased, altering the balance of forces until the stresses exceed the resisting soil strength. Undercutting at the toe of the slope by waves steepens the bluff and increases the shear stress.

One major type of slope failure is sliding. In this type of failure, the material generally moves along a single slide plane. Translational slides, which occur on slopes with little or no vegetation, are the most common form of slides along the City of St. Francis shoreline. This type of failure

Figure 2

TYPICAL PATTERN OF WAVES
APPROACHING A BEACH



Note: ≅ denotes approximately
Source: Hanson, Perry, and Wallace.

Because slope stability is influenced by dynamic factors, slope failure is a process that may occur in an unpredictable, abrupt fashion as opposed to a uniform, relatively continuous fashion. After each incremental slope failure, the soil masses tend to temporarily assume a stable configuration until the net effect of the many influencing factors once again decreases slope stability, thus precipitating another incremental failure.

Several factors affect the type of slope failure which occurs and the severity of that failure. The physical characteristics of the beach and bluff have a major influence on the resistance of the slope to failure. Numerous other factors affect the external stresses which are placed upon the slope, resulting in various types of failure. Among these factors is wave action, particularly during storms. When occurring concurrently with high lake levels, wave action can result in rapid and severe erosion of the toe of bluffs within the study area. This bluff toe erosion may cause instability of the entire bluff slope, causing ultimate recession of the bluff. Wave action also affects the orientation, width, slope, and substrate of beaches. Figure 2 illustrates the pattern of breaking waves as they approach a beach. Wave action is also important because of its potential for damaging shore protection structures such as revetments, bulkheads, breakwaters, and piers.

Waves may be characterized by their height, period or frequency, velocity, and length. Knowledge of these wave characteristics is necessary in order to predict wave energy against the beach and bluff, and to properly design shore protection structures. In deep water, the major determinants of wave height are wind speed, wind duration, and fetch length. In shallow water, wave height is determined by the height of the incoming deep water waves and by the slope of the beach and near-shore area. Wave period is defined as the time which elapses between two successive wave crests passing a fixed point. Wave velocity is defined as the speed and direction of a wave. Wave length is defined as the distance between the crests of two successive waves and is determined by wind speed, wind duration, and water depth.

The degree of wave energy affecting toe erosion is related to the slope of the beach and off-shore areas, the orientation of the beach in relation to storm wind and waves, the lake distance over which waves can develop, and the elevation of the water surface relative to the elevation of the base of the bluff. Most of the strong lake winds over Lake Michigan near the City of St. Francis approach from a northeast direction, a direction having a fetch--that is, the length of water over which the wind can blow unhindered--of up to 250 miles.[4] As these wind-generated waves approach the coast, wave refraction in shallow water directs the waves in a path more perpendicular to the shore. Various other wave phenomena, such as wave diffraction and reflection, occur as the waves encounter shore protection structures, including the Milwaukee South Shore breakwater.

Predicted Lake Michigan deep-water wave conditions during storms are set forth in Figure 3. The figure presents wave height and wave period predictions for various recurrence interval storm events. The reciprocal of the recurrence interval is the likelihood of that storm even occurring in any one year. For example, a 20-year recurrence interval storm event has a 5 percent chance of occurring during any given year. That same 20-year recurrence interval storm event has a 40 percent chance of occurring in any 10-year period, a 72 percent chance of occurring in 25 years, and a 92 percent chance of occurring in 50 years. Wave heights can range up to 24 feet, and wave period of frequency may range up to 11.5 seconds during major storm events. In general, the largest storm-generated waves are most likely to occur during winter, and least likely to occur during spring.[5]

Lake water-level fluctuations affect rates of wave-induced toe erosion. High water levels result in more rapid recession of the bluffs. When the water level is low, wave energy is expended as waves break along the beach. When water levels rise, waves can break directly on the toe of the bluff and erode the bluff material. The base of the slope is then undercut, creating unstable conditions in the slope above. This is eventually followed by slope failure and the movement of material down to the base of the bluff. As water levels decrease, the beach again widens and much of the wave energy is dissipated.

There is a time lag, however, between bluff recession rates and the decline in lake level because materials in the bluff take time to form a stable slope. Thus, even after water levels decline and wave erosion is decreased, bluff recession continues at a fairly high rate until the bluffs have reached a stable slope angle. Peak bluff-top recession rates typically occur about four years after a high water level within this portion of the Lake Michigan shoreline.

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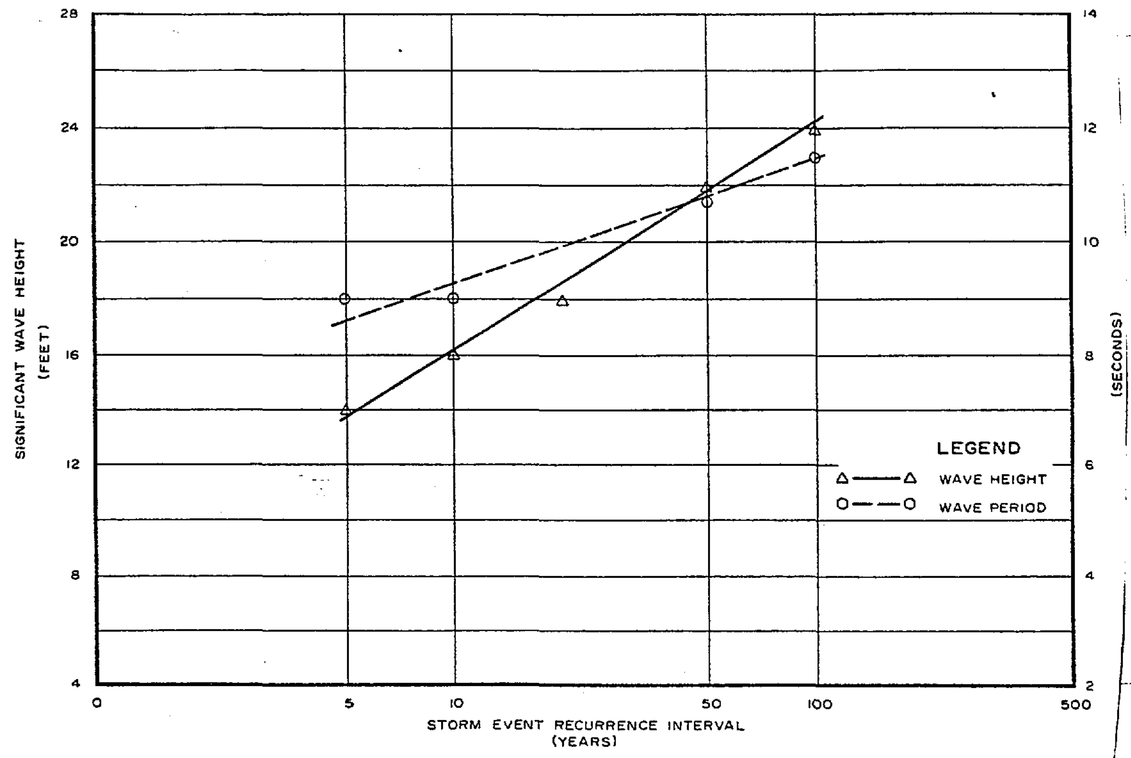
[4]J. P. Keillor and R. DeGroot, Recent Recession of Lake Michigan Shorelines in Racine County, Wisconsin, Volume I, Text, April 1, 1978.

[5]J. P. Keillor, University of Wisconsin-Sea Grant Institute, Letter to Earl K. Anderson, Port of Milwaukee Harbor Engineer, September 14, 1983.

Figure 3

PREDICTED LAKE MICHIGAN DEEP-WATER CONDITIONS DURING STORMS AT MILWAUKEE



NOTE: THE SIGNIFICANT WAVE PERIOD AND WAVE HEIGHT ARE THOSE AVERAGE CHARACTERISTICS EXHIBITED BY THE LARGEST ONE-THIRD OF THE WAVES OCCURRING DURING THE RECURRENCE INTERVAL STORM EVENT.

Source: J. P. Keillor, University of Wisconsin-Sea Grant Institute, Letter to Earl K. Anderson, Port of Milwaukee Harbor Engineer, September 14, 1983; U. S. Army Corps of Engineers, Design Wave Information for the Great Lakes, Report No. 3, Lake Michigan, Technical Report H-76-1, November 1976.

Since 1860, average annual surface elevations of Lake Michigan at Milwaukee have ranged from a low of 577.06 feet above National Geodetic Vertical Datum (NGVD)--also referred to as Mean Sea Level Datum--in 1964, to a high of 582.24 feet above NGVD in 1886 (see Figure 4). The level of Lake Michigan is a function of inflow from Lake Superior, stormwater runoff from the tributary land surface, precipitation falling directly on the lake, outflow from Lake Michigan through the Straits of Mackinac, evaporation from the lake surface, and resulting changes in the storage--volume of water--in the lake. The annual cycle in Lake Michigan water level elevations is shown in Figure 5. The highest water level elevations occur in June, July, and August, and the lowest water level elevations occur in January, February, and March. Generally, the lake levels rise from February through July and fall during the remainder of the year. In any one-year period, the range in base lake levels may be expected to be about one foot. The historic range between maximum and minimum monthly mean water levels is about five feet for all months of the year.

Figure 4

AVERAGE ANNUAL SURFACE WATER ELEVATION OF LAKE MICHIGAN AT MILWAUKEE: 1860-1980

Source: National Oceanic and Atmospheric Administration.

The anticipated occurrence of high Lake Michigan water levels was presented in a report prepared by the U. S. Army Corps of Engineers.[6] For various reaches of the Lake Michigan coast, the report includes estimates of the highest water levels along the open coast expected to be equaled or exceeded on an average of once every 10 years, as well as once every 50 years, 100 years, and 500 years. These levels were based on water level frequency curves derived by the Corps from the maximum instantaneous water levels recorded each year by the National Oceanic and Atmospheric Administration over an approximately 70-year period, adjusted to current outlet conditions. Lake Michigan levels on the St. Francis coast may be expected to equal or exceed maximum levels of 582.7 feet NGVD an average of once every 10 years, 583.6 feet NGVD every 50 years, 583.9 feet NGVD every 100 years, and 584.5 feet NGVD every 500 years. Even the 10-year recurrence interval maximum water level is higher than the maximum level shown in Figure 5, because the values shown in the figure are average annual surface water elevations, while the predicted recurrence interval eleva-

[6]U. S. Army Corps of Engineers, Report on Great Lakes Open Coast Flood Levels, February 1977.

tions are derived from maximum instantaneous levels. Prolonged storm periods of several days' duration may raise water levels by a foot or more along the city coastline.[7]

Ice formation influences bluff erosion and tends to contribute to a seasonal cycle in erosion. When stationary ice develops along the shore in winter, it may serve as a temporary protective barrier against wave action associated with winter storms, thereby reducing bluff erosion. When the ice is not stationary against the shore, however, floating ice chunks can scour the beaches and the bluff toe, thereby reducing the ability of the beach to dissipate wave energy and contributing to toe erosion. Floating ice fields, depending on wind conditions, may develop along the coast. Ice can also cause damage to structures which have been installed to protect the beach and bluff.

Groundwater seepage can also affect bluff stability in several ways. In most areas along the City of St. Francis shoreline, groundwater moves toward the lake and, in some places, discharges either at the toe of the bluff or from the bluff face. Saturated soil conditions decrease the grain-to-grain contact pressure in the soil and reduce the frictional resistance of the material to stress. Groundwater also adds weight to the bluff, further increasing stress on the slope. In addition, groundwater seepage creates a seepage pressure in the direction of water flow. This pressure is of particular importance in granular soils such as sands and silts and is of lesser importance when the clay content of the soils is fairly high. If groundwater actually discharges along the bluff face, some undercutting of materials may also occur. Removal of bluff materials by groundwater is especially important when sand layers either are interbedded with fine-grained materials or are present at the bluff top. When present on the top of the bluff, large amounts of water percolate through the sand until a less permeable material is reached, and the water then travels laterally toward the bluff face. Sapping of material may occur at the top of this permeable layer.

Vegetation can also have an effect on bluff stability and erosion. The above-ground portion of the vegetation physically intercepts raindrops, thereby reducing their potential to loosen particles on the bluff face, reducing the impact of wind, and serving to trap windblown sediment. The underground portion of vegetation serves to bind the unconsolidated material in place, to prevent slippage between soil layers parallel to the bluff face, and to retard surface wash and filter out the sediment carried by that wash. The roots of vegetation, however, may induce infiltration by slowing runoff and providing infiltration passages into the bluff face, thereby possibly contributing to a decrease in bluff stability as a result of increased groundwater content and level. Transpiration through vegetation can also help to remove groundwater from the bluff, however, and thereby contribute to its stability. Vegetation on the top of the bluff may serve to intercept and divert some surface runoff, thus preventing it from moving down the bluff face. Probably one of the most significant aspects of the lack of vegetation on a bluff face is that it serves as an effective indicator of recent erosion.

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[7] J. P. Keillor and R. DeGroot, Recent Recession of Lake Michigan Shorelines in Racine County, Wisconsin, Volume I, Text, April 1, 1978.

of high, steep waves. A beach is said to be stable, even though subject to storm and seasonal changes, when the long-term--several years or more--rates of supply and loss of material are approximately equal.

Sediment is transported parallel to the shoreline along the beach by longshore currents. Longshore currents are currents in the breaker zone running generally parallel to the shoreline and usually caused by waves breaking at an angle to the shoreline. Longshore currents transport sediment and other particulate matter--which is suspended in the current or bounced and rolled along the lake bottom--parallel to the shore. While the longshore currents within the coastal zone of St. Francis may move in either a northerly or southerly direction in response to the direction of the incident waves, the net sediment transport is to the south. Evidence of this fact is the tendency for beaches to exhibit accretion on the north side of groins, piers, and other structures while erosion occurs on the southerly side of such structures. The U. S. Army Corps of Engineers has estimated a net southward transport rate of 45,000 cubic yards of sediment annually along the littoral area of Lake Michigan between the Wisconsin Electric Power Company's Lakeside and Oak Creek power plants.[8]

EXISTING REGULATIONS PERTAINING TO SHORELAND DEVELOPMENT

The State of Wisconsin and the federal government have long been involved in the protection of public rights on navigable waters, while more recently water quality has become an important management concern. Of particular concern for coastal erosion management are the means by which state and federal agencies regulate various activities affecting the protection of the Lake Michigan shoreline. In addition, Milwaukee County has regulatory authority concerning certain types of shore protection and development measures within the County's shoreline.

The U. S. Army Corps of Engineers is the primary federal agency responsible for the regulation of structures and work related to surface waters. Initial Corps authority to regulate structures or work in, or affecting, navigable waters stems from the River and Harbor Act of 1899. Corps regulatory authority was expended with the passage of the Federal Water Pollution Control Act amendments in 1972. Section 404 of this act authorized the Corps to administer a permit program to regulate the deposition of dredged and fill materials into waters and related wetlands of the United States, as well as to regulate the construction of shore protection structures.

Although the State of Wisconsin, through the Department of Natural Resources, regulates shore protection-related activities throughout most of the Lake Michigan shoreline of the State under the provisions of Chapter 30 of the Wisconsin Statutes, the Department does not have such authority for the City of St. Francis shoreline because a Lake Bed Grant was issued to Milwaukee County for this shoreline area. The Lake Bed Grant, issued by the Wisconsin

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[8]U. S. Army Corps of Engineers, Section 103 Reconnaissance Report on Shore Erosion, Racine County, Wisconsin, 1977.

Legislature in 1933, provides Milwaukee County with regulatory authority to protect the public's interest for the bed of Lake Michigan out to 2,400 feet from the shoreline. The County administers a permit program for shore protection measures and dredge and fill activities which requires the submittal of a plan and which may require that certain conditions established by the County be met. The Wisconsin Department of Natural Resources does, however, have the authority under Section 401 of the Federal Water Pollution Control Act to review and grant water quality certification of federal actions which require a permit under Section 404 of the Act. This review, administered under Chap-NR 299 of the Wisconsin Administrative Code, is conducted to determine if the proposed activity will result in a discharge of wastes to surface waters, result in violations of applicable water quality standards, or interfere with public rights and the public's interest.

Because the entire shoreline within the City of St. Francis is owned by Milwaukee County or by the Wisconsin Electric Power Company, there has been no need to include provisions pertaining to Lake Michigan shoreline erosion hazards in the city zoning ordinance. There is also no county shoreland zoning ordinance that applies within the City of St. Francis, nor has the City found it necessary to adopt special shoreland zoning regulations.

EXISTING STRUCTURAL EROSION CONTROL MEASURES

Shoreland structural erosion control measures are intended to reduce coastal erosion by providing an artificial protective barrier against direct wave and ice attacks on the beach and bluff toe, by increasing the extent of the beach to absorb wave energy before the water reaches the bluff, by dissipating wave energy, and/or by stabilizing bluff slopes.

On-shore protective structures within the study area include revetments and a rubble mound porous dike. The revetments contain a flattened slope surface armored with erosion-resistive materials, such as concrete and natural rock rip-rap and underlaid by filter cloth or gravel. The dike, which encloses a pond, is also composed of rock and provides protection against wave action.

Breakwaters within the study area are protective structures built away from and parallel to the shore in deeper water. They provide dissipation of wave energy, thus reducing bluff toe erosion while reducing the strength of the longshore current immediately landward of the structures. However, breakwaters may accelerate beach and bluff erosion downdrift of the protected areas, as sediments settle in the sheltered water behind the breakwater.

Slope stabilization has been accomplished in some bluff areas by using earthmoving equipment to regrade the face of the slope to a flatter, more stable profile, thus accelerating the natural stabilization process. This approach is practical only if sufficient vacant land is available at the top of the bluff. Slope stabilization can also be accomplished through maintenance of a protective cover of vegetation.

At the present time, nearly 3,500 feet, or 36 percent, of the City of St. Francis Lake Michigan shoreland area is protected by on-shore structures. As shown on Map 7, all of the on-shore protection structures are located at, or adjacent to, the Wisconsin Electric Power Company power plant site. In addition, some protection against wave action is provided by the 4,600-foot-long portion of the Milwaukee South Shore breakwater which lies within the study area.

In 1922, the power company constructed a rubble mound porous dike due east of the main plant site, as shown on Map 7. The dike encloses a pond which, when in operation, was used as a circulating cooling pond with a maximum design flow of 632 million gallons per day. The dike extends 500 feet off-shore to a Lake Michigan water depth of approximately 18 feet, and is 1,750 feet long. Two general cross-sections were used in the construction of the dike, one for a water depth of less than 12 feet and one for a water depth equal to or greater than 12 feet. These cross-sections are shown in Figure 7. The core of the dike is composed of crushed limestone and is overlain by granite, rhyolite, quartzite, and dolomite stone.

Map 7

EXISTING SHORE PROTECTION STRUCTURES WITHIN THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELAND STUDY AREA

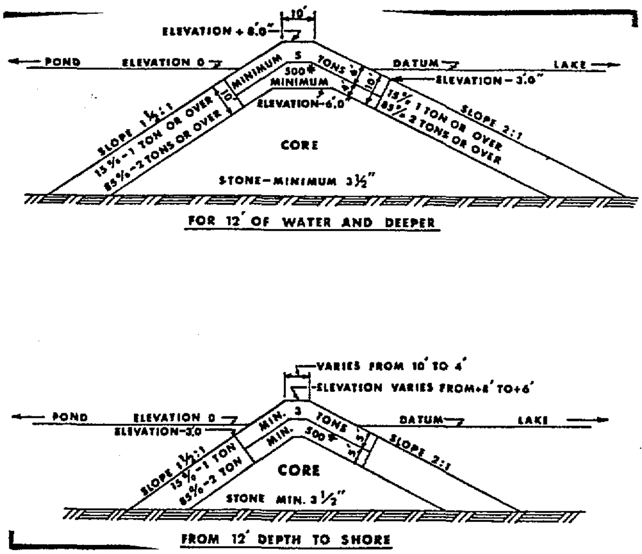
Source: SEWRPC.

In the mid-1930's, the power company constructed revetments north and south of the dike. These structures protect 1,700 feet of shoreline. Various-size concrete slabs and boulders were used to construct these original revetments. North of the dike the revetment extends for a distance of 900 feet, as shown on Map 7. This revetment was initially constructed between 1935 and 1938, but was more recently reconstructed with concrete slabs from demolished sidewalks and streets. Portions of the bluff behind it have been regraded to a more stable slope. The southern revetment was reconstructed in 1973 and covers approximately 800 feet of shoreline, extending from the dike to the drainage ditch south of the plant, as shown on Map 7. Shown in Figure 8 is a cross-section of the southern revetment as it was reconstructed in 1973. Generally, the revetment stands eight feet high from the toe of the bluff and extends outward 20 feet to the water line and an additional 22 feet into the lake. The revetment is underlain by a filter cloth. During the reconstruction of the revetment, the bluff behind it was regraded to a stable slope. The slope is well vegetated with grass and shrubs.

A Lake Michigan shore protection survey conducted in 1976 concluded that both revetments and the dike on the Wisconsin Electric Power Company property were

Figure 7

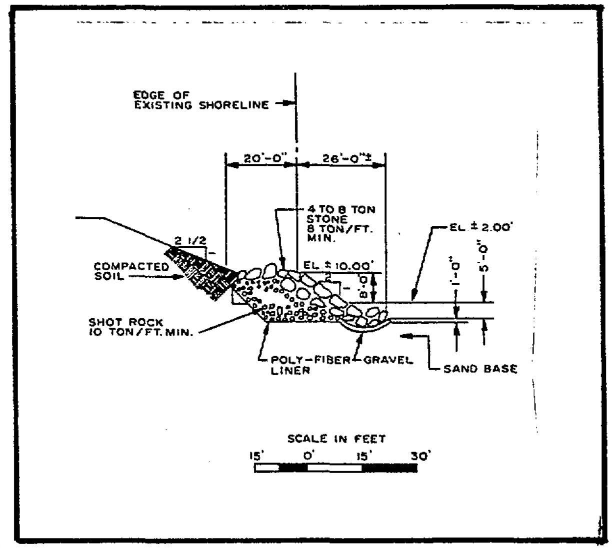
CROSS-SECTIONS OF THE WEPCO LAKESIDE POWER PLANT RUBBLE MOUND POROUS DIKE



Source: Wisconsin Electric Power Company.

Figure 8

CROSS-SECTION OF THE WEPCO LAKESIDE POWER PLANT REVETMENTS



Source: Wisconsin Electric Power Company.

functional, and did not require any major repairs.[9] Accelerated beach and bluff erosion downdrift of the protected areas were noted as adverse effects of the structures, however.

The southern extension of the Milwaukee outer harbor breakwater, known as the Milwaukee South Shore breakwater, serves as an off-shore protection structure for the northern portion of the study area. The South Shore breakwater was constructed by the City of Milwaukee Park Board in segments beginning in 1913. The construction of the breakwater that lies parallel to the City of St. Francis shoreline began in 1930. The first segment built extended for a distance of approximately 2,300 feet and required more than 100,000 tons of stone for completion. An additional 2,300 feet of breakwater constructed 200 feet from the first segment was completed in 1931, the southern 600 feet of which was built by The Milwaukee Electric Railway & Light Company, the predecessor company to the Wisconsin Electric Power Company. As shown on Map 7, the breakwater is located more than 1,000 feet off-shore at an approximate water depth of 20 feet.

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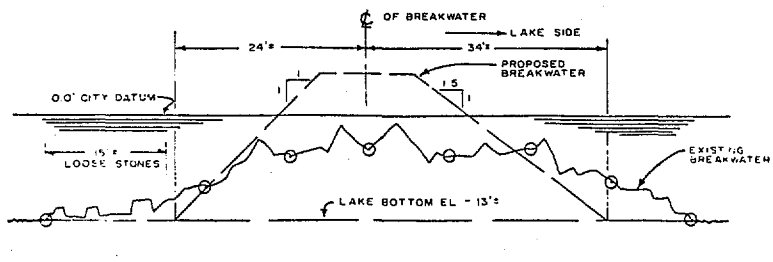
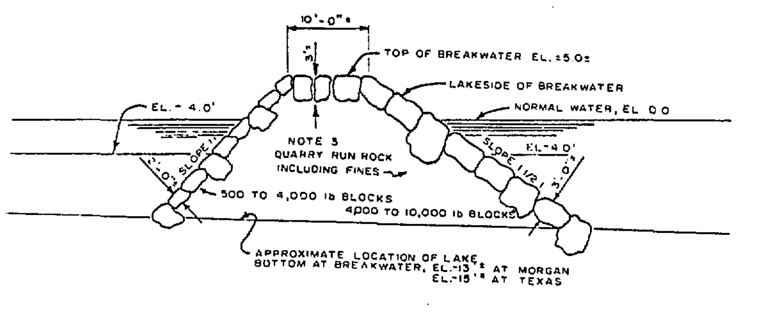
[9] D. M. Mickelson, et al., Shore Erosion Study: Technical Report--Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, 1977.

Figure 9

EXISTING AND PROPOSED MILWAUKEE SOUTH SHORE BREAKWATER PRACTICES AND PROPOSED CROSS-SECTION WITHIN THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELAND STUDY AREA



Design Specifications for Proposed Reconstructed Breakwater



Cross-Section Profiles for Existing Breakwater and Proposed Reconstructed Breakwater

Source: City of Milwaukee Department of Public Works.

Figure 9 shows a proposed cross-section for reconstruction of the breakwater, as well as a typical cross-section of the breakwater as it was surveyed in 1981. The breakwater consists of dolomite stone of varying size, weight, and quality. The breakwater is currently functional but, as shown in Figure 9, has experienced a significant amount of deterioration. In 1948, Milwaukee County assumed responsibility for maintaining the breakwater; however, very little maintenance has actually been performed. In 1980, Milwaukee County estimated that it would cost $8 million to rebuild the entire South Shore breakwater to its original form. Some bluff areas behind the breakwater continue to experience slope failure caused primarily by wave erosion of the bluff toe.

EXISTING COASTAL EROSION PROBLEMS

Coastal erosion includes erosion and recession of the beach and bluff. Bluff recession is the most serious Lake Michigan shoreline erosion problem in the City of St. Francis. Bluff recession results in the loss of extensive land areas; and the sometimes major, unexpected, and rapid slope failures caused by slumping and sliding may pose a threat to human safety. The erosion or accretion of the beaches is a related process in that the extent of the beach affects the degree of wave erosion at the bluff toe. As previously noted, other factors, some of them natural and some of them related to human activity, influence bluff stability either by altering the gravity-induced stresses which tend to cause bluff failure or by affecting the resisting strength factors which tend to maintain bluff stability.

Bluff Analysis Sections

The actively eroding bluff areas within the City were divided into six sections, each with similar physical and erosion-related characteristics. These six bluff analysis sections are shown on Map 8. Field surveys were conducted in December 1983 to delineate the section boundaries and to inventory the physical characteristics of, and identify the causes and types of, slope failure occurring within each section. Table 7 summarizes the physical and erosion-related characteristics of the six sections experiencing active bluff erosion.

Section 1 contains a relatively narrow--10 to 20 feet wide--beach and the highest bluffs--about 70 feet--in the study area. The bluffs are comprised of sand and gravel and layers of Oak Creek, New Berlin, and Tiskilwa tills. The primary cause of bluff recession is bluff toe erosion caused by wave action. Contained within the New Berlin till, which is exposed at the bottom 15 feet of the bluffs, are interbedded sand blocks. Groundwater seepage from these sand blocks, although not observed during the December 1983 field surveys, probably reduces the stability of this lower slope. Groundwater seepage also occurs at the top of the Oak Creek till which lies above the New Berlin till. Hence, the lower portion of the bluff has an extremely steep slope, as shown in Figure 10. Slumping is occurring in the Oak Creek till. This section has the greatest potential in the study area for large slumps to occur.

Map 8

BLUFF ANALYSIS SECTIONS WITHIN THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS

Source: SEWRPC.

Table 7

PHYSICAL AND EROSION-RELATED CHARACTERISTICS OF BLUFF ANALYSIS SECTIONS

Bluff Analysis Section	Shoreline Length (feet)	Beach Width (feet)	Beach Composition	Bluff Height (feet)	Bluff Composition	Groundwater Conditions	Cause and Type of Bluff Slope Failure
1	440	10-20	Sand, gravel, cobbles, and scattered large boulders	70	Oak Creek till at top of bluff, underlain by sand and gravel, underlain by another layer of Oak Creek till, underlain by New Berlin till, underlain by Tiskilwa till	Groundwater seeps occur at the bottom of the sand and gravel layer, and also in large sand blocks which are interbedded in the New Berlin till	Wave erosion is the primary cause of slope failure, although boulders in New Berlin till at base of bluff and in near-shore areas cause waves to break off-shore. Groundwater seepage reduces slope stability, particularly in till layers which contain interbedded blocks of sand. Small slumps were noted, especially in the Oak Creek till. Shallow slides also occur
2	600	10	Sand gravel, cobbles, and scattered large boulders	50-60	Sand and gravel at top of bluff underlain by New Berlin till. At southern end of section, Oak Creek till lies above New Berlin till	Although water-bearing strata were present, no seeps were noted in field survey. Groundwater may drain northward toward Section 3	Wave erosion is the primary cause of slope failure, although boulders in New Berlin till at base of bluff and in near-shore area cause waves to break off-shore. Sand and gravel above the till falls primarily as shallow slides, solifluction, and sand flows
3	160	10-20	Sand, gravel, and scattered large boulders	50	Laminated silt and sand at top of bluff, underlain by sand and gravel	Major groundwater seeps have formed a gully extending from the top of the bluff, and also discharge near the bluff toe	Bluff toe erosion by wave action is the primary cause of slope failure, although groundwater seepage also reduces slope stability near the gully and at the bluff toe. Failure occurs as shallow slides and sheet and rill wash, with some evidence of groundwater sapping at the gully and bluff toe, and of solifluction
4	440	10-20	Gravel, cobbles, and large boulders	50	Laminated silt and sand at top of bluff, underlain by sand and gravel, underlain by New Berlin till. In some areas, Oak Creek till lies between laminated silt and sand and sand and gravel	Major groundwater seeps occur at the top of the New Berlin till	Wave erosion is reduced because large boulders contained in New Berlin till at base of bluff and in near-shore area cause waves to break off-shore, thereby reducing wave energy. Groundwater seeps at top of New Berlin till reduce slope stability. Failure occurs as shallow slides, sheet and rill wash, and groundwater sapping
5	1,200	10-30	Sand, gravel, cobbles, and scattered small boulders	40-45	Laminated silt and sand at top of bluff, underlain by Oak Creek till. Small area at base of bluff is sand and gravel.	No major groundwater seeps were noted	Bluff toe erosion by wave action is the primary cause of slope failure. Failure occurs as shallow slides, solifluction, and sheet and rill wash
6	1,600	10-70	Sand and gravel	40-50	Oak Creek till at top of bluff, underlain by a layer of sand and gravel, underlain by another layer of Oak Creek till	Major groundwater seeps occur at the bottom of the sand layer, and particularly the sand and gravel layer	Bluff slope failure is less severe here than in the other sections because the bluffs are lower and the beach is wider and protected by a breakwater. Slope failure is caused by bluff toe erosion by wave action, and by the groundwater seepage at the bottom of the sand and gravel layer. Failure occurs as shallow slumps, slides, and sheet and rill wash

Source: SEWRPC.

Figure 10

BLUFF ANALYSIS SECTION 1

Source: SEWRPC.

Figure 11

BLUFF ANALYSIS SECTION 2

Source: SEWRPC.

As shown in Figure 11, Section 2 contains a narrow beach and bluffs 50 to 60 feet high. Sand and gravel comprises the top 25 to 40 feet of bluff, and is underlain by up to 30 feet of New Berlin and Oak Creek till. Some groundwater seepage may occasionally occur at the bottom of the sand and gravel strata, but none was observed during the December 1983 field surveys. Wave erosion at the bluff toe is the primary cause of bluff recession. The sand slopes on the top portion of the bluff are affected by shallow slides, solifluction, and sand flows.

Section 3 has a beach width of 10 to 20 feet and a bluff height of about 50 feet, as shown in Figure 12. The bluff is the only actively eroding area within the study area which contains no till; the bluff is comprised of laminated silt and sand, underlain by sand and gravel. Wave erosion is again the primary cause of bluff recession. Major groundwater seeps have formed a gully at the north end of the section. Groundwater sapping also occurs near the base of the bluff. As shown in Figure 12, slope failure occurs as shallow slides, solifluction, and sheet and rill wash.

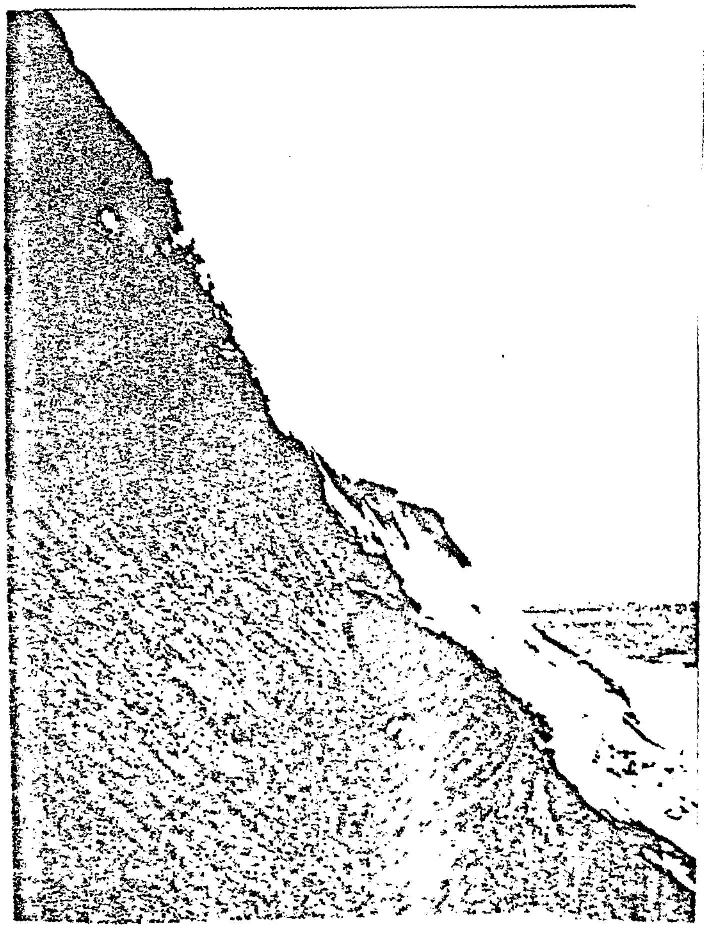
Figure 12

BLUFF ANALYSIS SECTION 3

SLOPE FAILURE CAUSED BY WAVE EROSION AT TOE OF BLUFF

SOLIFLUCTION

SHALLOW SLIDE

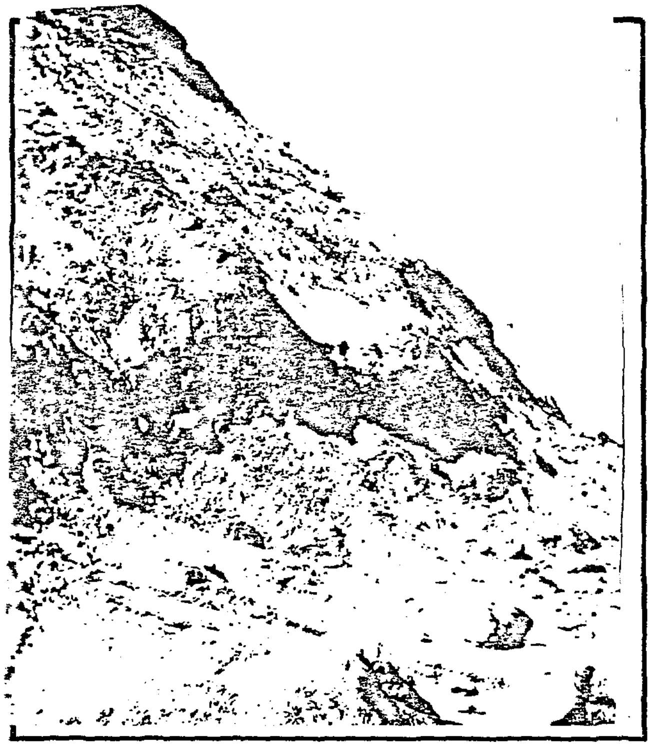


Source: SEWRPC.

Figure 13

BLUFF ANALYSIS SECTION 4

INSTABILITY OF BLUFF SLOPE
DUE TO GROUNDWATER SEEPAGE



GROUNDWATER SEEPAGE

Source: SEWRPC.

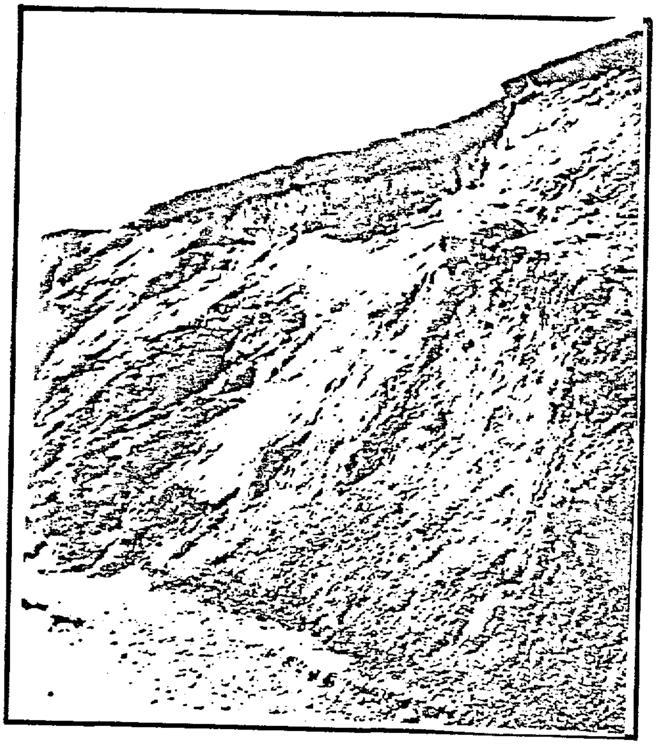
In Section 4, the beach is 10 to 20 feet wide and the bluff is about 50 feet high. New Berlin till again appears at the base of the bluff. On top of the New Berlin till lies sand and gravel and laminated silt and sand. As shown in Figure 13, large boulders contained in the New Berlin till are present at the bluff toe and in the near-shore area of the lake. These boulders provide some protection against wave action and, hence, this section extends into the lake relative to the adjacent sections. On top of the New Berlin till, groundwater seeps occur, reducing the stability of these lower slopes (see Figure 13). Slope failure occurs as shallow slides, sheet and rill wash, and groundwater sapping.

Compared to Sections 1 through 4, which are located south of the Wisconsin Electric Power Company power plant, Section 5 has a somewhat larger beach width--ranging up to 30 feet--and slightly lower bluff height--from 40 to 45 feet (see Figure 14). The bluff is comprised primarily of laminated silt and sand, underlain by Oak Creek till. No major groundwater seeps were noted during the field surveys. Wave erosion at the bluff toe is the primary cause of bluff recession. Slope failure occurs as shallow slides, solifluction, and sheet and rill wash.

Section 6, located north of the Wisconsin Electric Power Company power plant, is protected by the Milwaukee South Shore breakwater. As a result, the beach is wider--up to 70 feet--than south of the power plant. Bluff heights range

Figure 14

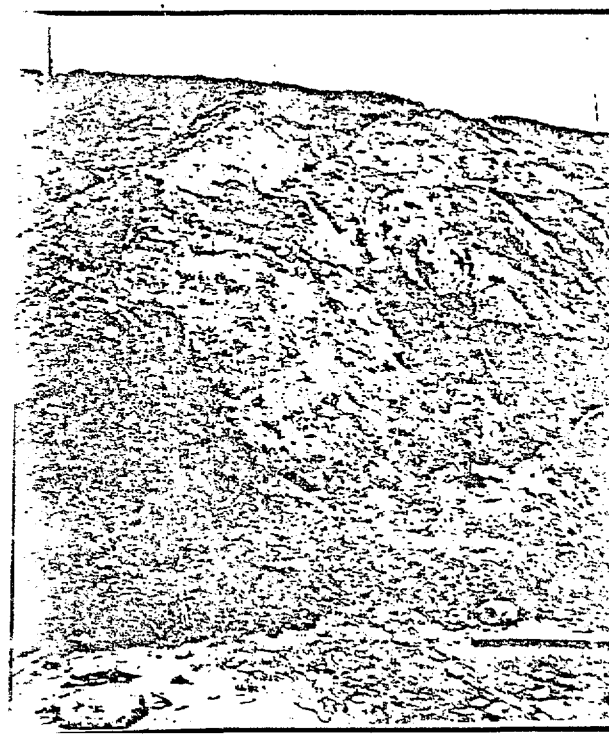
BLUFF ANALYSIS SECTION 5



Source: SEWRPC.

Figure 15

BLUFF ANALYSIS SECTION 6



ce: SEWRPC.

from 35 to 50 feet. The bluff is comprise rimarily of Oak Creek till, with a layer of sand and gravel lying near th iddle of the bluff. Wave erosion at the bluff toe is substantially reduced the breakwater and the relatively wide beach; nevertheless, wave erosion ains the primary cause of bluff recession. Groundwater seepage occurs at bottom of the sand and gravel layer, and is most severe toward the no ern end of the section. As shown in Figure 15, slope failure occurs as sh w slumps, slides, and sheet and rill wash.

Slope Stability Analyses

Bluff slope stability analyses are condu d to determine the likelihood of bluff slope failure within the various bl analysis sections; to determine whether the most likely failures are de seated slumps or shallow slides; to relate slope failures to bluff strata d groundwater conditions; and to determine stable slope angles for the bl fs. The slope stability analyses utilize geotechnical engineering techniqu to quantify and evaluate those stress and strength factors which affect e bluff slopes and which result in the observed bluff recession in the stu area. The results of the analyses were used in the design and development of ternative shore protection structures and in the determination of the stab bluff slopes used in the delineation of nonstructural setback distances.

The bluff-slope stability analyses conducted under this study provide a means for evaluating existing slope stability and for predicting bluff slope failure in those bluffs where rotational sliding is a major type of slope failure. Slope stability analyses for rotational slides are commonly used as an overall indication of the resistance of the slopes to all types of massive slope failures. Slope stability analyses were performed for the bluffs within each bluff analysis section using surveyed geometric profiles of the bluffs, laboratory analyses of bluff material properties, and a computer program based on the modified Bishop method of slope stability analysis.[10] The modified Bishop method was used to analyze the stability of the bluff slopes and to determine the shape and location of the probable sliding surface.

During the field surveys conducted in December 1983, a total of 12 bluff slope profiles were prepared for failing slopes which showed the angle and length of each section of the bluff with a substantially different slope. The profile sites were selected to be representative of bluff areas with different physical characteristics and different causes and types of slope failure. From one to three profiles were prepared for each bluff analysis section. The strata at each profile site were delineated, and grab samples of the different strata were collected. Laboratory tests were conducted on the soil samples to determine various properties related to stability.

Laboratory analysis of bluff material samples collected on December 10, 1983, was performed by the Department of Civil Engineering of the University of Wisconsin-Madison. The soil properties so determined and used in the slope stability analyses are set forth in Table 8 for all of the materials sampled in the study area. The laboratory analyses of bluff soils provided a quantitative determination of soil properties which affect the resistance of the soil to slope failure. The moisture content, liquid and plastic limits, silt and clay fraction, and friction angle of soil samples provide information useful in calculating the strength of forces within the soils which resist slope failure and which therefore tend to favor slope stability.

Two important indicators of soil properties are the liquid limit and the plastic limit. The liquid limit is defined as that water content level of a soil, expressed in percent dry weight, at which the soil begins to act as a viscous liquid. Measured liquid limits for soil samples collected within the study area ranged from 22 to 42 percent. The plastic limit is defined as the water content level at which the soil begins to act as a plastic. The difference between the liquid limit and the plastic limit is known as the plasticity index, and represents the range in water content through which the soil acts as a plastic, and may move laterally under load. The plasticity index is related to the presence of clay in the soil and is an indicator of the behavior of the clay particles in the soil under load when moisture is present. Plasticity index values measured within the study area ranged from 7 percent to 23 percent. With a known liquid limit and plasticity index, the measured moisture content of a soil sample can be used to estimate the behavior of that soil sample as a liquid or as a plastic. Measured moisture contents within the study area ranged from 10 percent to 34 percent.

The fraction of the soil which is composed of silt- and clay-sized particles is an indicator of the resistance of the soil materials to slope failure. Soils containing significant amounts of clay and silt are referred to as

[10] A. W. Bishop, "The Use of the Slip Circle in the Stability Analysis of Slopes," Geotechnique, Volume 5, No. 1, 1955, pp. 7-17.

Table 8

SELECTED PROPERTIES OF BLUFF MATERIALS WITHIN THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS

Soil Sample Number[a]	Description	Moisture Content (percent)	Liquid Limit (percent)	Plasticity Index (percent)	Silt and Clay Fraction (percent)	Effective Friction Angle (degrees)	Unified Soil Classification
1	Laminated Silt and Clay....	22.6	42.5	23.1	--[b]	30	CL
2	Laminated Silt, Sand, and Gravel...............	20.4	24.9	12.1	--[b]	33	CL
3	Oak Creek Till............	22.7	38.7	21.7	92.2	31	CL
4	Sand and Gravel with Till Deposits............	23.1	37.8	21.0	92.6	31	CL
5	Sand and Gravel...........	15.4	--[c]	--[c]	0.4	31	SP
6	Laminated Silt and Sand....	33.8	22.1	6.7	95.3	31	CL-ML
7	New Berlin Till...........	10.1	24.0	10.7	61.4	34	CL

[a]All samples were collected on December 10, 1983.

[b]Parameter not measured under this study.

[c]The liquid limit and plasticity index could not be determined for sand and gravel because the soil was nonplastic.

Source: T. B. Edil and D. J. Mickelson, 1983.

cohesive soils, whereas granular soils such as gravel and sand are referred to as cohesionless soils. Because of low permeability, cohesive soils are often poorly drained and exhibit excess pore pressure, which may reduce slope stability. The soils sampled within the study area had a large range in textures, with the silt and clay fraction ranging from less than 1 percent to 95 percent.

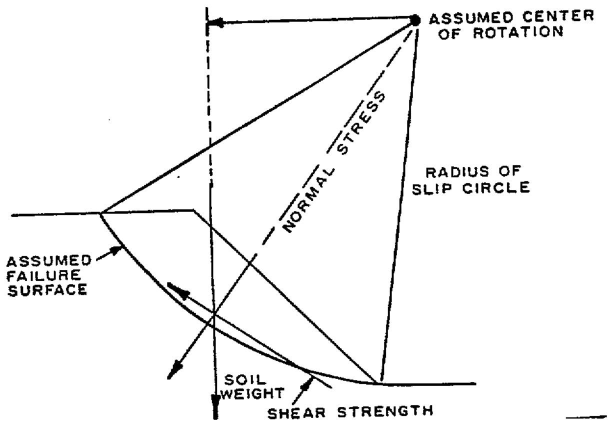
The effective friction angle of a soil is another important indicator of the ability of a soil to resist slope failure. The effective friction angle is defined as a coefficient related to the frictional resistance of the soil to shearing when placed under stress. For sand, the effective friction angle is that angle at which the soil would achieve a stable slope if no groundwater was present within the soil. Effective friction angles are generally higher for soils that have a higher density, well-graded particles, and angular grains than for soils that have a lower density, uniform-size particles, and rounded grains. Effective friction angles within the study area were relatively uniform, ranging from 30 to 34 degrees.

All bluff soil samples were classified on the basis of the Unified Soil Classification system. This system classifies soils primarily for engineering purposes. The soils within the St. Francis bluffs were classified as CL, ML, and SP soils. CL soils are relatively fine-grained, impervious soils with a high clay content, low plasticity, and a liquid limit of less than 50 percent. CL soils generally have very low shear strengths. ML soils are fine-grained, fair to poorly drained soils with a high silt and silty clay content, low plasticity, and a liquid limit of less than 50 percent. ML soils tend to have low shear strengths. SP soils are coarse-grained, well-drained soils which are poorly graded, with little or no fine-grained particles. SP soils tend to have a higher shear strength than do ML and CL soils. Typical soil properties known for these Unified Soil Classification groups were used--in conjunction with the measured values set forth in Table 8--in the slope stability analyses.

The stability of the bluff slopes was analyzed using the modified Bishop method computer program to determine the least stable circular failure surfaces, as shown in Figure 16. Once the potential failure surfaces had been selected using the program, the shear stress and shear strength along the assumed failure surface could be determined. If the rotational forces--or stresses--causing failure were greater than the rotational forces--or strength parameters--resisting it, the slope was considered unstable. If the strength forces exceeded the stress forces, the slope was assumed to be stable. The slope stability analyses assumed and evaluated a variety of failure surfaces in order to identify the most critical--and most likely--failure surface.

Figure 16

CONCEPT OF SLOPE STABILITY ANALYSIS FOR ROTATIONAL SLIDES



Source: C. C. Mathewson, Engineering Geology, C. E. Merrill Publishing Company, 1981.

The shear strength and shear stress forces were used to calculate a safety factor for each assumed failure surface. This safety factor is defined as the ratio of the shear strength to the shear stress along the failure surface. Thus, a safety factor less than or equal to one indicates imminent failure, and the lower the safety factor, the more likely the slope will fail. Safety factors greater than one imply a margin of safety for slope stability based on the assumed soil characteristics and slopes. It is important to note that as slope conditions change, the safety factor will also change. The critical failure surfaces set forth for the bluff slope profiles in this chapter are those surfaces which have the lowest safety factors, and thus are most likely to fail.

Bluff Profiles: The bluff profiles set forth in Figures 17 through 28 show the length and slope of the land surface from the top of the bluff to the Lake Michigan water level. The profiles thus represent both the bluff and beach areas. The profiles also show the stratigraphy of the bluff, and the probable maximum groundwater elevation. The probable maximum groundwater elevations were used in the slope stability analyses and are based on the observed stratigraphy. Within most profiles, the probable maximum groundwater elevations were assumed to lie directly beneath the highest strata which is relatively permeable. Within profiles C and D, however, the probable maximum groundwater elevations were assumed, based on the field survey of bluff material characteristics, to lie within a layer of permeable sand and gravel, rather than directly beneath it. The groundwater elevations shown on the profiles are the maximum levels expected and indicate where the highest seepage zones may exist. The results of the slope stability analyses--the assumed critical failure surfaces and the calculated safety factors--are also shown on the profiles.

Map 9 shows the locations of the 12 profiles prepared within the study area. The profiles depict unstable bluffs which are currently receding. The profile sites were selected to represent typical physical characteristics, as well as typical slope failure within the respective analysis sections. More than one profile is provided for those bluff analysis sections that exhibit substantial variation in physical or erosion-related characteristics. Because soil moisture conditions vary with time and because a time lag often exists between steepening of the slope and the actual slope failure, it is possible for slopes with safety factors of less than one to exist for several years without failing. Low safety factors do indicate that slope failure is imminent, however. In fact, a very large slump occurred in Bluff Analysis Section 1 in the spring of 1984. This type of large, deep-seated failure near the bluff top of Section 1 was predicted by the slope stability analysis conducted using the bluff profiles observed in December 1983.

Profile A--The very steep, 72-foot-high bluff at profile A shown in Figure 17 is representative of Bluff Analysis Section 1. Groundwater seepage at the top of the Oak Creek till and from interbedded sand layers in the New Berlin till results in an unusually steep lower slope (C-D). Although the profile shows the accumulation of slope failure debris at the toe of the bluff (D-E), wave erosion at the bluff toe is the primary cause of slope failure at this profile site. The three critical failure surfaces shown on the profile have safety factors ranging from 0.75 to 0.97, indicating unstable slopes.

Profile B--Profile B, presented in Figure 18, shows a 56-foot-high bluff typical of Bluff Analysis Section 2. Groundwater seepage occurring at the top of the Oak Creek till may result in the relatively steep slope shown at B-C. A large amount of debris has accumulated at the bluff toe (C-D), but active wave erosion is the primary cause of slope failure at this profile site. The slope stability analysis indicated an unstable slope with a safety factor of 0.89.

Profile C--Bluff Analysis Section 3, which is composed entirely of sand, silt, and gravel, is illustrated for a 54-foot-high bluff by profile C, shown in Figure 19. Wave erosion, as well as groundwater seepage, at the bluff toe (D) are the primary causes of the slope failure. Several recent shallow slides were observed at the profile site. With a calculated safety factor of 0.77, the slope stability analysis indicated that the slope is unstable.

Profile D--Profile D, shown in Figure 20, is one of three profiles which represent Bluff Analysis Section 4. The 50-foot-high bluff experiences severe groundwater seepage at the top of the New Berlin till (D). This groundwater seepage, along with wave erosion, reduces the stability of this lower slope and causes ultimate recession of the bluff. The slope stability analysis indicated safety factors of 0.98 for the entire bluff slope, and 0.67 for the lower and middle portions of the bluff slope.

Profile E--Profile E, shown in Figure 21, is similar to profile D and is also located in Bluff Analysis Section 4. Severe groundwater seepage was observed at the top of the New Berlin till. Profile E exhibits recent recession of the bluff top. A safety factor of 0.80 was calculated for the entire 54-foot-high bluff slope.

Profile F--Figure 22 shows profile F, the third profile within Bluff Analysis Section 4. Although wave erosicn of the bluff toe occurs, the slope is relatively smooth because boulders located in the New Berlin till at the bluff toe provide some protection against wave action. The wave action removes the debris which is deposited at the bluff toe, but undercutting was not observed. Such boulders were also located at profile sites D and E, but lesser degrees of wave erosion protection were provided. Groundwater seeps were again observed at the top of the New Berlin till. A slope stability analysis indicated imminent failure near the top of the 54-foot-high bluff, with a safety factor of 0.75.

Profile G--Profiles G, H, and I are located within Bluff Analysis Section 5. Within Section 5, the New Berlin till is located beneath lake level. Hence, large boulders are not present at the bluff toe to provide protection against wave action. Groundwater seepage was not observed in Section 5 during the

December 1983 field survey, although it is expected that groundwater does occasionally discharge from the bluff slopes. Profile G, shown in Figure 23, contains a relatively steep beach (C-D) and lower bluff slope (B-C). Slope stability analyses indicated a safety factor of 0.85 for the entire 48-foot-high bluff slope. However, a safety factor of 0.69 was calculated for the middle portion of the bluff.

Profile H--Profile H within Bluff Analysis Section 5, shown in Figure 24, represents a 49-foot-high bluff with an actively receding bluff top. Although wave erosion remains the primary cause of the slope failure, the lower bluff slopes (B-C and C-D) were not steep and were covered by debris which had fallen from the upper portion of the bluff. The most likely slope failure would occur on the upper bluff slope, with a calculated safety factor of 0.80.

Profile I--Figure 25 shows profile I within Bluff Analysis Section 5. This profile site contains a relatively wide beach (E-F-G) and a near-vertical bluff toe (D-E). The upper bluff slopes (A-B-C) showed evidence of recent failure by slumping and sliding. A safety factor of 0.99 was calculated for the entire 48-foot-high bluff, indicating a marginally unstable slope. This was the highest safety factor calculated within the unstable bluff portion of the study area, although a portion of profile K also had a safety factor of 0.99.

Profile J--Profiles J, K, and L are located within Bluff Analysis Section 6 north of the power plant site. Profile J, as shown in Figure 26, shows a relatively smooth, 38-foot-high bluff. Wave erosion at the bluff toe (C-D), as well as groundwater seepage at the bottom of a layer of sand, reduces the stability of this slope. Within the entire bluff analysis section, wave erosion is reduced by the off-shore Milwaukee South Shore breakwater. A safety factor of 0.78 was calculated for this bluff slope, indicating that additional slope failure can be expected.

Profile K--Profile K within Bluff Analysis Section 6, as shown in Figure 27, contains relatively mild upper bluff slopes (B-C-D), accumulated bluff debris on the lower bluff slope (D-E-F), and wave erosion at the bluff toe (E-F). Groundwater seepage occurs at the bottom of the sand layer. The slope stability analysis indicated safety factors of 0.97 to 0.99 for the 46-foot-high bluff.

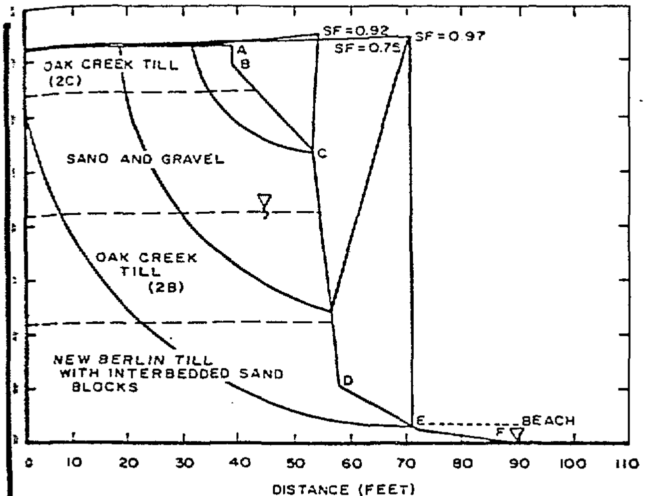
Profile L--Profile L, shown in Figure 28, represents a smooth slope within Bluff Analysis Section 6. The 36-foot-high bluff exhibited groundwater seepage at the bottom of a layer of sand and gravel. The beach was relatively wide (34 feet), yet wave erosion remained the primary cause of slope failure. Slope instability was indicated by a calculated safety factor for the entire bluff slope of 0.91.

BLUFF RECESSION RATES

The rate of shoreline erosion and bluff recession may be estimated by measuring the change in location of a bluff edge over a specified time period. Bluff recession rates for the City of St. Francis were measured for two different time spans using Regional Planning Commission ratioed and rectified, 1 inch equals 400 feet scale aerial photographs. All measurements on the aerial photographs were made parallel to the U. S. Public Land Survey Section line which forms the southern boundary of the study area. The measurements were corrected for minor variations in map scale and for the angle of the shoreline in order to represent bluff recession perpendicular to the shoreline.

Figure 17

BLUFF PROFILE A WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

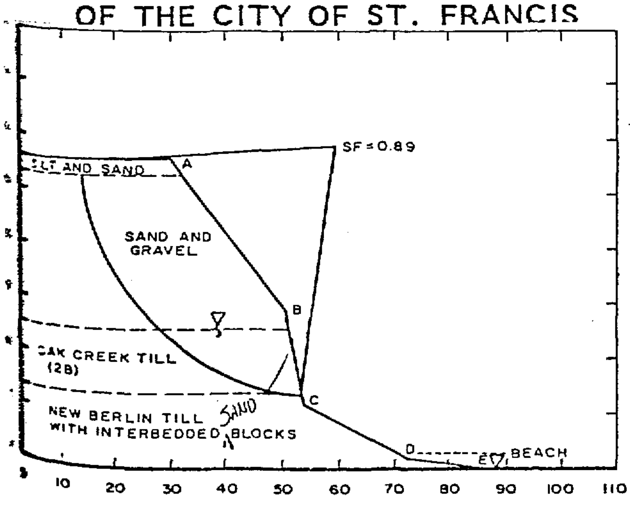
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 18

BLUFF PROFILE B WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

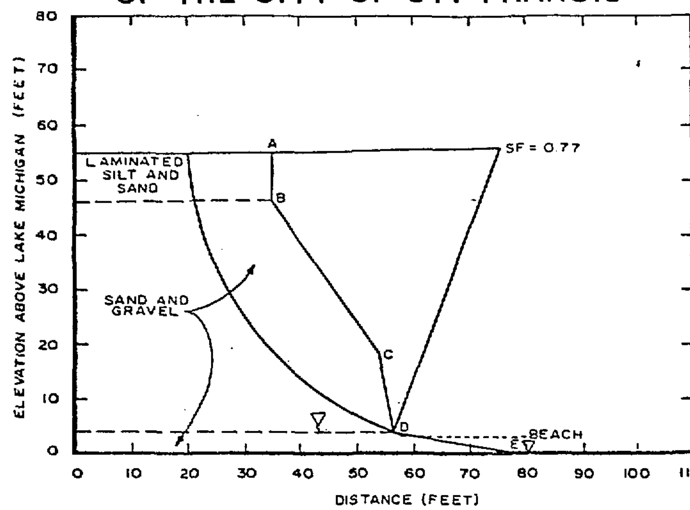
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 19

BLUFF PROFILE C WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

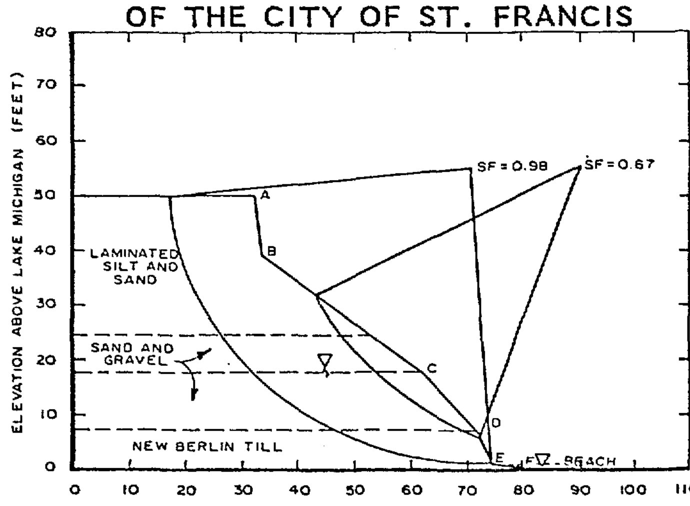
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 20

BLUFF PROFILE D WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

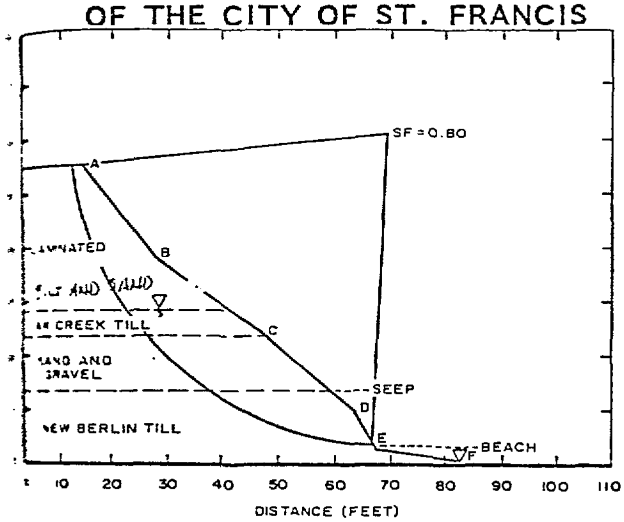
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 21

BLUFF PROFILE E WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

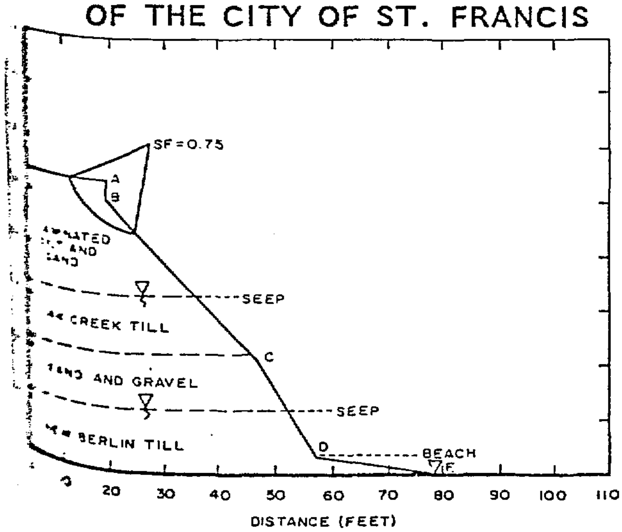
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 22

BLUFF PROFILE F WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

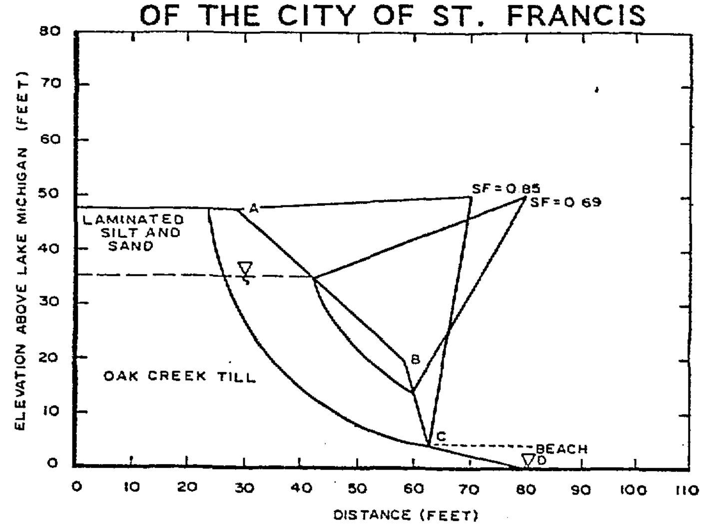
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 23

BLUFF PROFILE G WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

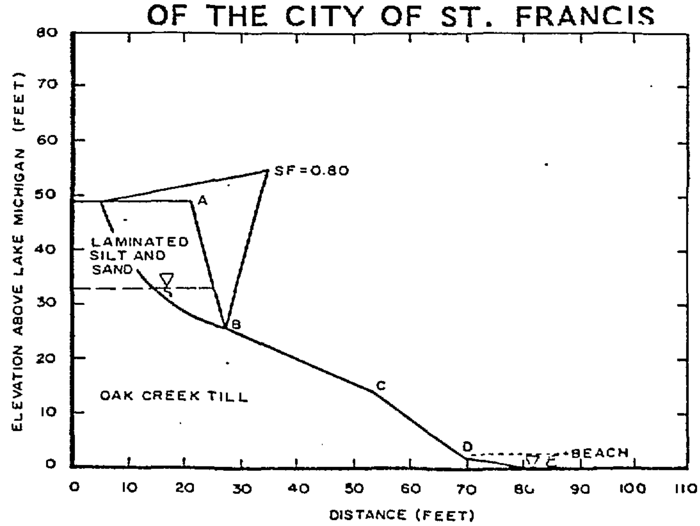
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 24

BLUFF PROFILE H WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

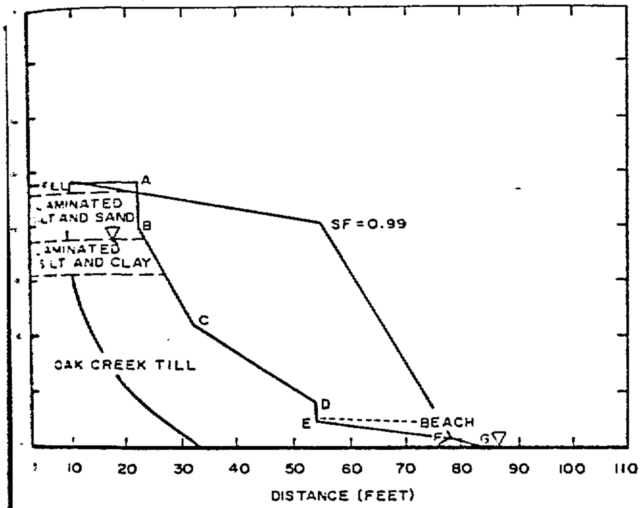
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 25

BLUFF PROFILE I WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

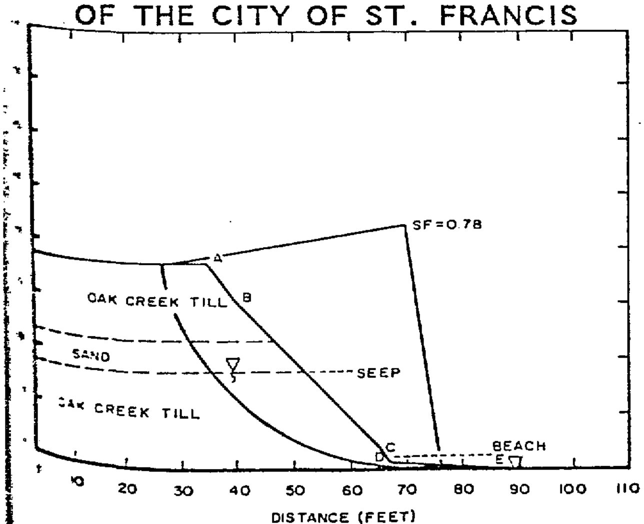
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 26

BLUFF PROFILE J WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

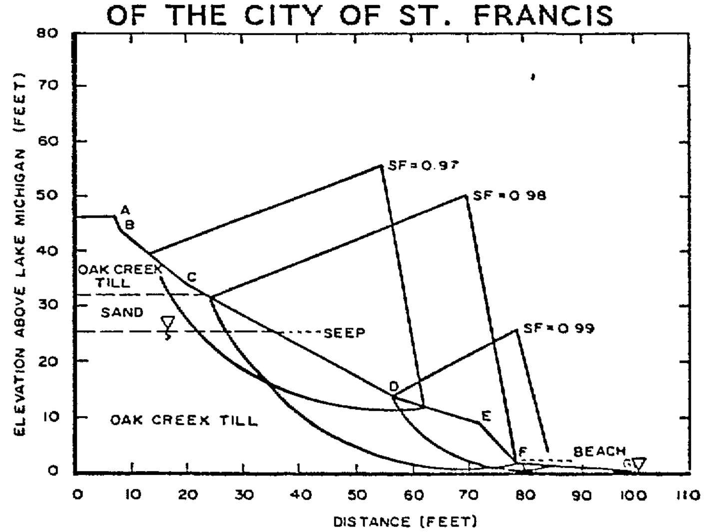
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 27

BLUFF PROFILE K WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

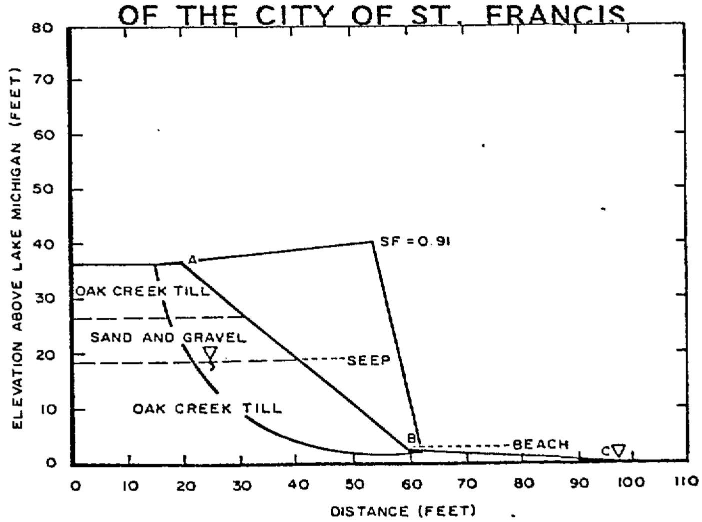
ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Figure 28

BLUFF PROFILE L WITHIN THE LAKE MICHIGAN SHORELAND OF THE CITY OF ST. FRANCIS



LEGEND

ASSUMED MAXIMUM GROUNDWATER ELEVATION

LAKE SURFACE

Source: T. B. Edil and D. M. Mickelson, and SEWRPC.

Map 9

LOCATION OF BLUFF PROFILE SITES WITHIN THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS

Source: SEWRPC.

Map 10

LAKE MICHIGAN BLUFF RECESSION REACHES IN THE CITY OF ST. FRANCIS

Source: SEWRPC.

Bluff recession was measured at intervals of 200 feet--the interval length being measured perpendicular to the section line--along the actively eroding portions of the study area shoreline except Bluff Analysis Section 3, which has only 160 feet of shoreline. These intervals define the boundaries of 19 bluff recession reaches, which are shown on Map 10. The shoreline length of these reaches ranges from 160 feet to 360 feet, with the combined length of the bluff recession reaches totaling 4,440 feet.

Table 9 presents the measured recession rates for the time periods 1963 through 1980 and 1970 through 1980 for each bluff recession reach. Shoreline length and the volume of bluff material lost for each reach are also presented in the table. The recession rates for the period 1963 through 1980 range from 0.2 foot per year to 5.6 feet per year, with a shoreline length-weighted mean of 2.7 feet per year. The highest recession rates measured were located in Bluff Analysis Section 1, with a mean-weighted recession rate of approximately 5.0 feet per year. Reaches with consistently low recession rates were located within Bluff Analysis Section 6, where the shore is protected by the Milwaukee South Shore breakwater.

Table 9

BLUFF RECESSION RATES ALONG THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELINE

Bluff Analysis Section	Bluff Recession Reach	Actively Eroding Shoreline Length (feet)	Annual Recession Rates (feet per year)		Annual Volume of Bluff Material Loss (cubic feet per year)[a]
			1963-1980	1970-1980	
1	1	200	5.6	5.3	76,200
	2	240	5.0	4.5	81,600
Subtotal		440	5.3	4.9	157,800
2	3	200	4.8	4.6	55,700
	4	200	3.3	5.1	34,300
	5	200	2.7	3.1	28,100
Subtotal		600	3.6	4.2	118,100
3	6	160	4.7	5.1	17,600
Subtotal		160	4.7	5.1	17,600
4	7	240	2.0	3.6	24,000
	8	200	2.4	3.0	24,000
Subtotal		440	2.2	3.3	48,000
5	9	280	3.7	4.5	47,700
	10	200	3.2	6.3	28,200
	11	280	4.1	6.3	50,500
	12	240	3.2	4.1	32,300
	13	200	2.0	3.3	16,800
Subtotal		1,200	3.3	4.9	175,500
6	14	360	0.2	0.0	3,600
	15	200	0.5	0.9	4,200
	16	240	0.3	0.6	2,900
	17	280	2.0	1.4	22,400
	18	280	0.8	0.8	9,400
	19	240	2.8	2.7	25,500
Subtotal	--	1,600	1.1	1.0	18,000
Total	--	4,440	2.7	3.2	535,000

[a]Based on recession rates for 1963-1980.

Source: SEWRPC.

For the period 1970 through 1980 the recession rates ranged from zero to 6.3 feet per year, with a mean recession rate of 3.2 feet per year. The highest recession rates occurred in portions of Bluff Analysis Section 5. The lowest recession rates were again located in Section 6.

The 1963 through 1980 average annual recession rates may be generally lower than the 1970 through 1980 rates because Lake Michigan water levels were at record lows during the early 1960's. Low lake levels may be expected to result in lower recession rates because the beaches would be wider and the bluff toes thus less susceptible to wave attack.

The Wisconsin Electric Power Company has mapped the location of the shoreline and the bluff edge for selected years between 1917 and 1980.[11] Recession rates measured from the power company maps were similar to those measured from

[11]Wisconsin Electric Power Company, property plat south of Lakeside power plant building, 1980.

the aerial photographs. This indicates that the Commission aerial photograph measurements of bluff recession rates are reasonable representations of recession rates observed over longer periods of time.

The volume of bluff material lost by erosion annually is also set forth in Table 9. Bluff recession, as measured from 1963 through 1980, results in the loss of about 0.3 acre of land each year containing approximately 535,000 cubic feet of bluff material. Although only 24 percent of the actively eroding study area shoreline--or 11 percent of the total study area shoreline--exhibits a recession rate exceeding four feet per year, that 24 percent accounts for about 53 percent of the total bluff material loss in the study area.

SUMMARY

This chapter presents an inventory of certain elements of the natural resource base relevant to coastal erosion and related land use management, summarizes existing land use and zoning patterns, and sets forth the findings of an inventory and analysis of the types, causes, and rates of shoreline erosion and bluff recession occurring within the City of St. Francis. This information is necessary for the delineation of those land areas which may be expected to be affected by bluff recession, for the selection and evaluation of structural and nonstructural shoreline erosion management measures, and for the consideration of alternative land uses for the study area. Natural resource data on geology and glacial deposits, soils, bluff and beach characteristics, groundwater resources, and climate are presented.

The City of St. Francis shoreline is underlain by Precambrian, Cambrian, Ordovician, and Silurian bedrock comprised primarily of dolomite, shale, sandstone, and crystalline rock. The bedrock is covered by unconsolidated glacial deposits which range up to 100 feet in thickness. Several layers of glacial debris, including the Oak Creek Formation, the New Berlin Formation, and the Zenda Formation, can be identified on the eroding bluff faces along the City's Lake Michigan shoreline.

Soil properties influence the rate of stormwater runoff and the severity of surface erosion. Soil properties are also an important consideration in the evaluation of suitable land uses for an area. About 53 percent of the coastal erosion study area is covered by Ozaukee soils, which have a low infiltration capacity, low permeability, and poor drainage. About 44 percent of the study area is covered by disturbed soils, the area so covered comprising generally the Wisconsin Electric Power Company power plant site. The remaining 3 percent of the study area is covered by water enclosed by the power company dike.

Bluff heights along the shoreline range up to nearly 70 feet above beach levels. About one-half of the shoreline has bluffs ranging from 40 to 50 feet in height. The most dominant bluff material identified was the Oak Creek till. This material was the predominant material along 65 percent of the actively eroding shoreline. Other common bluff materials found were sand and gravel, and silt and sand. The bluff slopes along about 54 percent of the shoreline were stabilized and covered with vegetation. The composition of the bluffs was not identified in these stable areas.

The most common beach materials found were sand, gravel, cobbles, and boulders. The most extensive beaches, exceeding 60 feet in width, were found to be located in the northern portion of the study area and were composed of sand

and gravel. About 28 percent of the shoreline had a beach width ranging from 1 foot through 20 feet; about 17 percent of the shoreline had a beach width ranging from 21 through 40 feet; about 9 percent of the shoreline had a beach width ranging from 41 through 60 feet; and about 15 percent of the shoreline had a beach greater than 60 feet wide. About 31 percent of the shoreline had no defined beach.

Along the City of St. Francis shoreline, groundwater generally flows toward Lake Michigan. Two major aquifers underlie the coastal area: the deep sandstone aquifer and the Niagara dolomite aquifer. In addition, the sand and gravel glacial deposits that lie above the Niagara bedrock may act as water-bearing units. There are numerous groundwater discharges and seepages on the bluff slopes, contributing to the instability of the slopes.

Climate impacts on coastal erosion include freeze-thaw actions within bluff material, high surface runoff from frozen soils, lake ice effects, and high surface runoff and soil erosion during intense storm events. Frozen ground and snow cover may be expected throughout approximately four months each fall and sleet. Lake ice formation begins in late November or December and ice breakup normally occurs in late March or early April.

The City of St. Francis coastal erosion study area encompasses a total of about 162 acres. The two major land use categories within the study area are unused urban land, which accounts for about 70 acres, or 43 percent of the study area, and communications and utilities, which accounts for about 50 acres, or 31 percent of the study area.

Zoning ordinances are important land use regulations. Under the present zoning ordinance in effect in the City of St. Francis, the study area is divided into three zoning districts--institutional, industrial, and residential--all of which permit urban development.

Approximately 80 percent of the land in the study area is owned by the Wisconsin Electric Power Company. All of the facilities and buildings within this property are located on the fence-enclosed, 76-acre parcel of land referred to as the main power plant site. The remaining 54 acres of land owned by the power company are vacant. A portion of Milwaukee County's Bay View Park is located in the northern portion of the study area.

Bluff erosion is of particular concern in the study area because it results in property loss and may pose a threat to human safety. Bluff erosion may occur as toe erosion, slumping, sliding, flow, surface erosion, and solifluction. Slope failure is often an unpredictable, abrupt process which is constantly being altered by numerous factors. Factors affecting bluff erosion include the physical characteristics of the bluff and beach, wave action, lake level fluctuations, ice formation, groundwater seepage, surface runoff, and vegetative cover.

Shoreland development and activities are regulated by federal, state, and local units and agencies of government. The U. S. Army Corps of Engineers is the primary federal agency responsible for certain structures, dredging, and wetland protection structures. The City of St. Francis zoning ordinance is generally devoid of provisions pertaining to Lake Michigan shoreline erosion hazards, and no county shoreline zoning ordinance applies within the City.

On-shore and off-shore protection structures have been installed to provide an artificial protective barrier against direct wave and ice damage to the beach and bluff toe, to increase the extent of the beach, to dissipate off-shore wave energy, and to stabilize bluff slopes. On-shore protection structures within the study area include a rubble mound porous dike and two revetments which extend north and south of the dike. The Milwaukee South Shore breakwater provides additional protection to the northern portion of the study area.

A detailed inventory of the physical characteristics and erosion-related characteristics of the actively eroding bluffs in the City of St. Francis was conducted in December 1983. The results of the inventory indicated that the primary cause of bluff recession in the study area is bluff toe erosion caused by wave action. Groundwater seepage also is a major cause of slope failure in some portions of the study area. Shallow sliding is the most common type of slope failure on the St. Francis bluffs.

Bluff profiles were prepared for selected sites along the City's shoreline. The profile sites were selected to be representative of bluff areas with different physical characteristics and different causes and types of slope failure. Each profile showed slopes, the lengths of different slope sections, and the composition of the bluff. For each of the profiles, a slope stability analysis was conducted to evaluate existing slope stability and predict future bluff slope failure. The results of the analyses were used in the selection and development of alternative shore protection measures.

Bluff recession rates for the City of St. Francis study area were measured using the Regional Planning Commission aerial photographs taken periodically from 1963 through 1980. For the period 1963 through 1980, about 24 percent of the actively eroding portions of the study area shoreline exhibited bluff recession rates of less than 1.0 foot per year. About 10 percent of the shoreline exhibited a bluff recession rate exceeding 5.0 feet per year. The highest recession rate measured from 1963 through 1980 was 5.6 feet per year, which occurred in the southernmost reach of the study area. The mean recession rate over the period 1963 through 1980 was 2.7 feet per year. In general, the average annual bluff recession rates measured over the period 1970 through 1980 were slightly higher than the annual recession rates measured over the period 1963 through 1980. Bluff recession in the study area results in the loss of about 535,000 cubic feet of bluff material annually.

Chapter III

EVALUATION OF COASTAL EROSION PROBLEMS AND CONTROL MEASURES

INTRODUCTION

Shoreline erosion and bluff recession along Lake Michigan is a natural phenomenon which is causing the loss of shoreland area in the City of St. Francis. The identification of the shoreland areas which are expected to be affected by shoreline erosion and bluff recession is essential to the evaluation of structural and nonstructural erosion control measures for the shoreland area. The purpose of this chapter is to describe the extent of shoreline erosion and bluff recession which may be expected to occur over time along the Lake Michigan shoreline of the City of St. Francis, to evaluate alternative structural shore protection measures, to identify erosion risk distances and setback distances for new urban development which are related to the erosion risks, and to provide criteria which relate shoreline erosion to land use management, construction activity, and stormwater management. This information is intended to enable city officials and other concerned and affected parties to better assess potential erosion losses and to agree on those erosion control and land use management measures recommended in Chapter IV of this report. The sound evaluation of shoreline erosion and its management helps ensure that development and redevelopment of the study area will occur with full knowledge of the required shore protection measures and the suitability of various land uses and land management activities for shoreland areas.

The first section of this chapter following this introduction describes the analytic procedures and criteria used to evaluate alternative structural shore protection measures; to identify and map the erosion risk distances; to calculate setback distances for new urban development; and to select proper land use management practices such as construction site erosion control and stormwater management practices for shoreland areas. The second section evaluates alternative shore protection measures for the study area. The third section delineates the erosion risk distances and setback distances from the existing shoreline as identified under a 50-year time period if additional shore protection structures are not implemented, and the erosion risk distances and setback distances if additional shore protection structures are implemented. The fourth section presents proper land use management measures, and the fifth and final section summarizes the chapter.

ANALYTIC PROCEDURES AND CRITERIA

The analytic procedures and criteria set forth in this chapter relate to shoreline erosion control with both structural and nonstructural measures. This section describes the methodologies used to evaluate shoreline erosion and bluff recession and the various means of either controlling or reducing the damages from that erosion and recession. These same procedures can be applied in the detailed design of development proposals and in the detailed engineering analysis of shore protection measures.

Structural Shore Protection Measures

In order to properly consider alternative structural shore protection measures, detailed, site-specific evaluations are required of the physical characteristics of the beach and bluff, wave and ice conditions, the causes of erosion, the degree of hazard posed by erosion, the intended use of the shoreline, the existing value of the property to be protected, and the resources which can be committed to the undertaking. In addition, in selecting a shore protection structure, the initial cost of the structure must be considered, along with the availability of needed materials and expertise and the frequency, cost, and convenience of maintenance. Structural shore protection measures which are known to be effective require a substantial capital investment, and entail a considerable maintenance cost. The existing shore protection structures in the study area are described in Chapter II.

Effective shore protection may require a combination of bluff toe protection, surface water and groundwater drainage control, and bluff slope stabilization. The effectiveness of structures can be assured only if proper structure repair and maintenance is provided. Shore protection structures may be provided if it can be shown that such structures will effectively reduce shoreline erosion and not adversely affect adjacent sections of the shoreline or impair public rights in navigable waters; that the structures will not preclude adequate public access, use, and enjoyment of the shoreline environment; and that any adverse impacts on fish and wildlife resources caused by the structures will be minimized or compensated for by providing fish and wildlife preservation measures.

A comparison of selected characteristics of shore protection structures is set forth in Table 10. Data are presented only for those structures and erosion control measures which may be applicable to the City of St. Francis shoreline. These structures and control measures include revetments, bulkheads, groins, off-shore breakwaters, surface water and groundwater drainage controls, and bluff slope regrading and revegetation measures. The table presents certain requirements for successful application of the structures, lists the advantages and disadvantages of each structure, and notes the compatibility of the structure with alternative shoreline uses. These data serve as the basis for determining which structures should be evaluated in detail for selected shoreline reaches.

Analytic procedures and general design criteria for different types of shore protection structures are set forth in Table 11. The analysis of the need for, and selection of, shore protection structures should include identification of the causes of shoreline erosion and bluff recession, consideration of wave conditions and off-shore lake bottom profiles, and determination of the availability of sand being transported in near-shore currents. In addition, soil analyses and slope stability analyses should be conducted, and surface water and groundwater drainage characteristics should be examined. The design criteria in the table relate only to the preliminary design and sizing of shore protection structures; detailed design criteria for structures are set forth in the U. S. Army Corps of Engineers' Shore Protection Manual (1977). The criteria set forth in the table include the selection of a design lake level and design wave; the provision of measures to protect against structure flanking, scouring, overtopping, and undercutting; the provision of adequate surface

Table 10

COMPARISON OF SHORE PROTECTION STRUCTURES

Shore Protection Structure	Protection Provided	Requirements	Advantages	Disadvantages	Compatibility With Alternative Shoreline Uses[a]				
					Walking	Swimming	Fishing	Boating	Aesthetics
Revetment	Protects the bluff toe against wave action	Bluff slope stabilization is required above revetment	Ease of maintenance. Flexible, durable	Loss of beach in front of revetment may be intensified. Heavy equipment required for installation	Fair	Poor	Poor	Poor	Fair
Bulkhead	Protects the bluff toe against wave action. Retains and prevents sliding of bluff	Bluff slope stabilization is required above bulkhead	Uniform appearance. Often maintenance-free. May provide good access to shoreline	Loss of beach in front of bulkhead may be intensified. Special equipment may be needed for installation. Bulkheads are generally not flexible and are expensive to repair	Good	Fair	Good	Fair	Fair
Groin	Traps sand in near-shore currents to create or extend a beach and thereby reduce wave action on toe of bluff	Sufficient sand availability in near-shore currents is required. Artificial beach nourishment could be required	Beach may serve as a recreation area. Groins may be flexible and maintenance-free	Trapping the sand supply may reduce the available sand for down-current beach areas	Good	Good	Good	Good	Good
Off-shore Breakwater	Reduces wave action upon beach and bluff toe. Also provides shelter for small boats	No special requirements	New breakwater could form an extension of the existing Milwaukee South Shore breakwater. Use of shoreline is not restricted	Heavy equipment mounted on barges may be required for installation and maintenance	Good	Good	Good	Good	Good
Bluff Regrading and Revegetation	Stable bluff slope is provided which, if properly protected, will prevent further bluff recession. Surface soil erosion is controlled and stormwater runoff can be reduced	Bluff toe protection and, where necessary, surface- and groundwater drainage control must be provided	A stable, well-vegetated bluff slope can be aesthetically pleasing and suitable for a wide range of shoreline activities. Bluff slopes may be planted with maintenance-free vegetation	Upland areas will be lost as bluff slope is regraded to a stable slope. These upland areas, however, would be subject to a high risk of erosion if the bluff slope were not regraded	Good	Good	Good	Good	Good
Surface Water and Groundwater Drainage Controls	Surface water drainage reduces surface erosion of exposed bluff soils and prevents gullying. Groundwater drainage reduces seepage and stability of slopes by reducing hydrostatic pressure and preventing sapping of bluff materials	Drainage controls should be implemented together with bluff slope regrading and bluff toe protection. Detailed analysis of groundwater system is required	Proper drainage will improve the stability of bluff slope and protective structures. Drainage facilities are relatively maintenance-free and should not limit the use of the shoreline	None	Good	Good	Good	Good	Good

[a] Use compatibility shown is for typical structures. Modifications to the design and construction of the structures may reduce shoreline use limitations.

Source: SEWRPC.

Table 11

RECOMMENDED ANALYSIS PROCEDURES AND GENERAL DESIGN CRITERIA FOR SHORE PROTECTION MEASURES

Shore Erosion Problem	Potential Applicable Shore Protection Structures	Recommended Analysis Procedures	Recommended General Design Criteria
Bluff Toe Erosion	Revetment, Bulkhead, Groin, Off-shore Breakwater	1. Identify shoreline reaches where bluff toe erosion significantly contributes to bluff slope instability. 2. Determine lake bottom profiles off-shore of proposed structure and 300 feet on both sides of the structure, from the structure out to a water depth of at least 12 feet 3. Consider design wave height and wave direction, and the erosive impacts of wave action on the proposed structure 4. Determine whether enough sand is contained within the near-shore lake currents to support the maintenance of a beach with the use of groins. Consider impacts on down-current beach areas	1. Size the structure for design waves expected for a 100-year recurrence interval high lake level, or 583.7 feet above National Geodetic Vertical Datum. The 100-year recurrence interval high lake level is defined as instantaneous static lake level with a 1 percent chance of exceedance in any given year. Wave height and wave run-up effects are not reflected in the 100-year level 2. Select an appropriate design wave for structure design. Generally, flexible structures, such as revetments, require a lower design wave than more rigid structures, such as bulkheads. The design wave should be tsser of: a) the maximum wave height generated by wind acting along the critical fetch, or b] the maximum wave breaker height that can reach the site during design water level conditions. In other words, if the wind can produce a larger wave than can be supported at the site, the available depth will control, not the wind 3. Provide measures to protect the base of the structure from wave scouring 4. Design loose rubble revetment structures with a slope not greater than one vertical on two horizontal 5. Avoid structural damage or erosion on the landward side of the structure by preventing the overtopping of the structure by storm waves, or by providing for the positive drainage of any water which overtops the structure 6. Provide measures to prevent excessive erosion along the flanks of the structure 7. Provide adequate bedding materials to prevent undercutting of the structure. Loose rubble revetment structures should extend at least one design wave height below the lake bottom
Bluff Slope Instability	Regrading of Bluff Slope, Revegetation	1. Identify shoreline reaches which have unstable bluff slopes and determine cause of instability 2. Evaluate bluff slope stability analyses and identify stable slope angles 3. Conduct a thorough site analysis to ensure successful revegetation, including climate, soils, slope, and water availability	1. Regrade bluff to indicated stable slope 2. Provide adequate surface water drainage to prevent excessive surface erosion, and adequate groundwater drainage to to help stabilize bluff slope. Provide bluff toe protection 3. Follow proper procedures for species selection, site preparation, planting techniques, and follow-up care 4. Select plant species which blend in with the shoreline environment, and which are suitable for desired shoreline uses 5. Utilize proper construction erosion control measures to prevent excessive erosion prior to vegetative cover growth
Groundwater Seepage	Groundwater Drainage Systems: Trench Drains, Horizontal Drains, or Vertical Well Pumping Systems	1. Identify shoreline reaches where groundwater seepage significantly contributes to bluff slope instability 2. Collect and identify soil borings at bluff and back from bluff 3. Identify soils and sediments exposed at bluff face 4. Determine soil drainage characteristics 5. Identify artesian aquifers and measure artesian hydrostatic pressures 6. Determine groundwater seasonal fluctuations 7. Conduct long-term soil stability analysis to identify those reaches which require seepage control to provide a stable bluff slope	1. Properly locate and size drainage facilities to prevent seepage from the face which reduces slope stability 2. Discharge water to a surface water system or to the base of the bluff
Excessive Surface Water Runoff and Soil Erosion	Channels, Diversions, Culverts, Storm Sewers, Energy Dissipaters	1. Identify shoreline reaches where surface runoff significantly contributes to bluff slope instability 2. Evaluate peak flow discharges and flow velocities under proposed future land use conditions for the study area 3. Identify existing gullies and areas of excessive sheet and rill erosion	1. Adjust stormwater drainage systems, assuming the layout of streets for all proposed future land use development in the study area, to the topography in order to minimize grading and drainage problems, to utilize to the fullest extent practicable the natural drainage system, and to provide the most economical installa tion of a gravity flow system 2. Design stormwater drainage systems for new development within the study area which do not create new drainage or flooding problems, or intensify existing problems at the shoreline 3. Locate and design stormwater drainage outlets to avoid discharging surface runoff over the top of the bluff, unless suitable conveyance facilities are provided to accommodate the flow without causing soil erosion or reducing the stability of the bluff slope 4. To prevent excessive scouring of open drainage channels, limit flow velocities during the design storm to five feet per second for turf-lined channels, and to 10 feet per second for concrete-lined channels. Limit turf-lined side slopes to a maximum of one on two and one-half 5. Provide energy dissipation measures where the velocity of overland flow is excessive, or where water flow is concentrated in erodible areas

Source: SEWRPC.

water and groundwater drainage; the selection of proper plant species and planting procedures for revegetation of the bluff slope; and the use of proper stormwater management techniques.

Erosion Risk Distances and Setback Distances

The delineation of areas with a high risk of erosion involves the prediction--based on analyses of existing and historic shoreline conditions and of the pertinent physical characteristics of the shoreline set forth in Chapter II--of future bluff recession rates both with and without structural shore protection measures. The estimated future bluff recession rates were based on the assumption that recession will continue at the same average rate as it has historically occurred. The historic recession rates used were those measured by the Regional Planning Commission for the period 1963 through 1980. High erosion risk areas are delineated by determining the distance from the existing bluff edge which will be affected by recession of the bluff over time, and by the regrading of the bluff slope as required to achieve a stable slope. This combined distance is referred to herein as the erosion risk distance. If adequate shore protection structures are provided, the erosion risk distance consists solely of the distance required to provide a stable slope.

The distance required for regrading of the bluff to achieve a stable slope is included in the erosion risk distance for two reasons. First, the stable slope distance serves as a safety factor. It cannot be assumed that the bluff face will remain at its existing slope, and the potential exists for the bluff slope to rapidly, and sometimes catastrophically, recede to a more stable slope. Second, for shoreline reaches currently unprotected by shore protection structures, the stable slope distance allows, at some future date, the opportunity to properly construct an adequate shore protection structure, which would include bluff slope stabilization.

Setback distances from the existing bluff edge for new urban development were identified under both nonstructural--without shore protection--and structural--with shore protection--alternatives. Setback distances are comprised of the erosion risk distance plus a minimum facility setback distance. The minimum facility setback distance is intended to provide a safety factor, to maintain aesthetics at the bluff edge, to allow for installation of surface water and groundwater drainage systems at some future date, and to prevent the location of major facilities too close to the bluff edge, which would increase the shear stress on the bluff slope.

Nonstructural Erosion Risk Distances and Setback Distances: A procedure was developed for delineating the erosion risk distances from the bluff edge assuming the use of nonstructural erosion control measures only; that is, assuming that no additional structural erosion control measures would be provided. Nonstructural erosion risk distances are comprised of a bluff recession distance over a given time period, plus the distance required to grade the bluff face to a stable slope. Erosion risk distances were delineated for a 50-year period of continued bluff recession along the entire shoreline within the City. The face of the bluffs was assumed to be graded to a stable slope of approximately one on two and one-half, or about 22°. This assumption is discussed further below.

Nonstructural setback distances for new buildings and facilities are established as the sum of the nonstructural erosion risk distance and a minimum facility setback distance. Minimum facility setback distances are presented below. The concepts used in estimating nonstructural erosion risk distances and attendant facility setback distances are illustrated in Figure 29.

Structural Erosion Risk Distances and Setback Distances: A procedure was also developed for delineating the erosion risk distances from the bluff edge assuming the use of structural shore protection measures. If the shoreline is to be provided with additional structural protection measures, the rate of bluff recession was assumed to be zero once the structural measures were in place, the bluff toe protected, and the bluff slope stabilized. A structural erosion risk distance was defined as that distance required to form a stable bluff slope of one on two and one-half, or about 22°.

A structural setback distance was established as the sum of the structural erosion risk distance and a minimum facility setback distance. The procedure used to estimate structural erosion risk distances and setback distances is shown in Figure 30. Structural setback distances would also apply to those portions of the Lake Michigan shoreline which are currently stabilized, even if no shore protection structure is in place.

Stable Slope Angles: The use of an ultimate stable bluff slope of one on two and one-half was identified on the basis of the December 1983 field survey results. This slope was similar to stable slopes along the Lake Michigan bluffs reported by Edil and Vallejo.[1] Another report by Vallejo and Edil[2] noted that, given certain physical soil characteristics, the ultimate stable slope may be expected to vary in relation to the height of the groundwater level--measured from the base of the bluff--to the height of the bluff. For the City of St. Francis shoreline, the ultimate stable slopes may be expected to range from a minimum of 16°, if the height of the groundwater is three-fourths or more of the height of the bluff, to a maximum of 34°, if no groundwater is contained within the bluff. This information could be used to develop differing stable slopes along the shoreline, but was not used to calculate stable slopes for specific reaches of the shoreline in this study because:

1. Groundwater levels, and specifically seepage zones, are highly variable on a seasonal and annual basis.

2. Surveys of groundwater seepage zones were conducted during only limited time periods. Substantial variation in seepage conditions was noted during these surveys.

3. Within the City of St. Francis shoreline, the overall phreatic surface of the groundwater is beneath the bluffs. Within the bluffs, only localized seepage zones, or seasonally high groundwater levels, exist.

[1]T. B. Edil and L. E. Vallejo, "Mechanics of Coastal Landslides and the Influence of Slope Parameters," Engineering Geology, Vol. 16, 1980, pp. 83-96.

[2]L. E. Vallejo and T. B. Edil, "Design Charts for Development and Stability of Evolving Slopes," Journal of Civil Engineering Design, Vol. 1, No. 3, 1979,. pp. 231-252.

Thus, different stable slopes would exist for different portions of the same bluff.

4. Groundwater conditions can change significantly as the bluff recedes and strata of permeable bluff materials are eroded, covered, or disturbed.

Therefore, a stable slope angle of one on two and one-half, or approximately 22°, is used in this study for the coastal bluffs evaluated. This stable slope angle represents an appropriate conservative estimate of stable slopes expected under a full range of groundwater conditions.

Land Use Management Related to Shoreland Development

Land use development and land management activities within the study area require consideration of many complex, interrelated factors. Because of competing land use demands and because the Lake Michigan shoreline is a valuable limited resource, priorities can be established to encourage those types of land uses which are appropriate within the shoreland area. In general, land uses which are most appropriate for shoreland development are those which significantly benefit, or are significantly enhanced by, a shoreland location, and those which do not increase the risk of erosion damage or interfere with the control of shoreline erosion. Potential future land uses for the study area may include residential use, park and open space, or lakefront-oriented commercial or institutional uses. These uses may not be equally suitable for the study area. Careful evaluation of each development proposal will be necessary to determine its conformance with shoreland objectives and other local development needs and goals.

This report evaluates only those aspects of land use development and land management activities which directly affect, or are affected by, shoreline erosion or the structural or nonstructural management of such erosion. The study thus identifies the risk of erosion damage presented by various land uses and land management activities and describes the suitability of various shore protection measures for potential development of the study area. The following criteria have been established to help evaluate land use impacts on shoreline erosion and its control:

1. Development of the study area should not significantly increase the bluff recession rates or reduce the stability of the bluff slopes; if the risk of erosion and bluff recession is increased by the development, adequate mitigative shore protection measures should be undertaken.

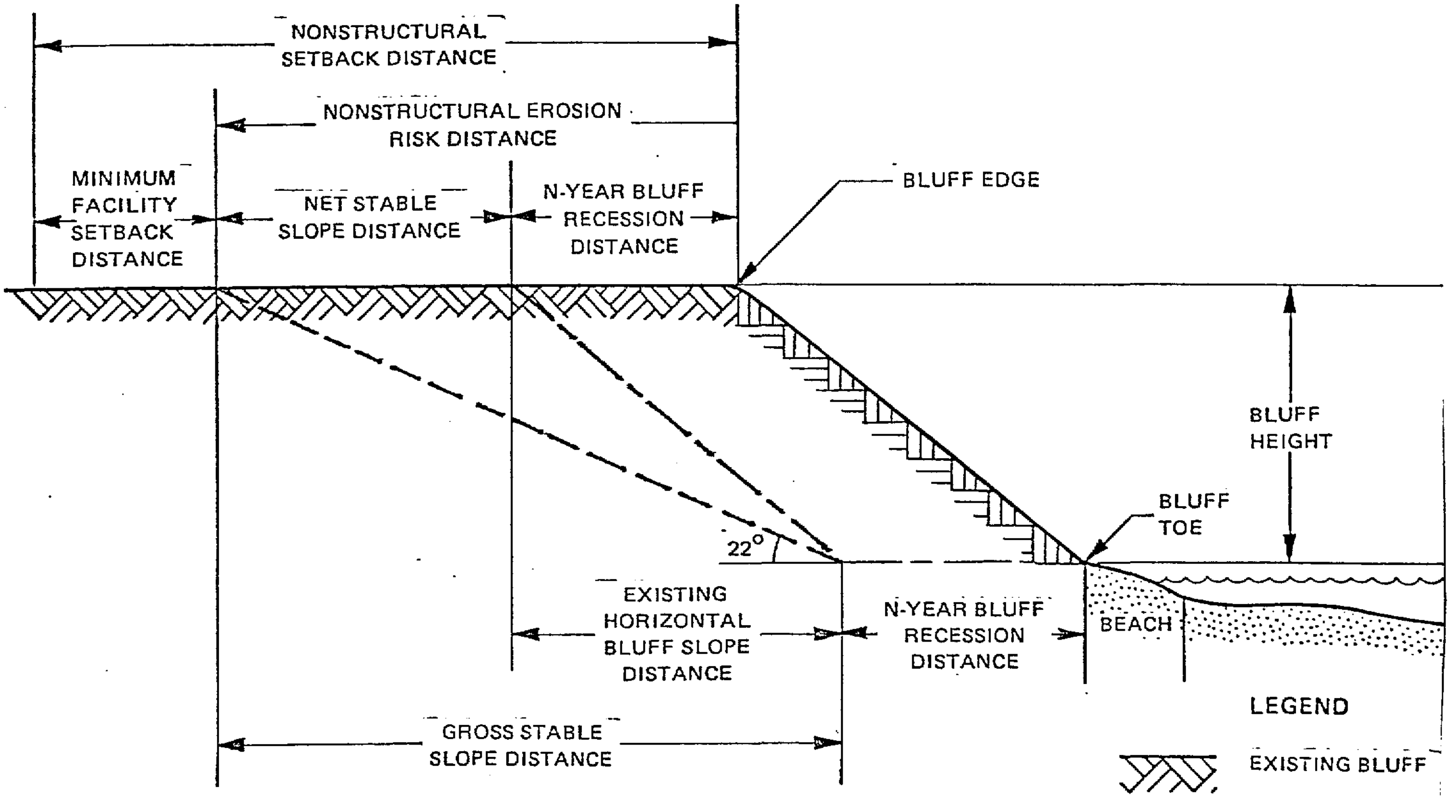
2. The selection of shore protection measures should be coordinated with the determination of future land uses in the study area.

3. Structural and nonstructural minimum facility setback distances should be identified for land uses based upon the size and type of facilities and buildings constructed, and upon the extent and type of use of the bluff top, bluff slope, and beach areas.

4. Whenever practicable and economically feasible, the selected shore protection structures should be compatible with the types of shoreline uses which would likely be supported by the potential land uses, and which are desired by the residents of the City of St. Francis.

Figure 29

PROCEDURE UTILIZED TO ESTIMATE NONSTRUCTURAL EROSION RISK DISTANCE AND NONSTRUCTURAL SETBACK DISTANCE



NONSTRUCTURAL EROSION RISK DISTANCE = NET STABLE SLOPE DISTANCE + N-YEAR BLUFF RECESSION DISTANCE

NONSTRUCTURAL SETBACK DISTANCE = NONSTRUCTURAL EROSION RISK DISTANCE + MINIMUM FACILITY SETBACK DISTANCE

WHERE: NET STABLE SLOPE DISTANCE = GROSS STABLE SLOPE DISTANCE - EXISTING HORIZONTAL BLUFF SLOPE DISTANCE

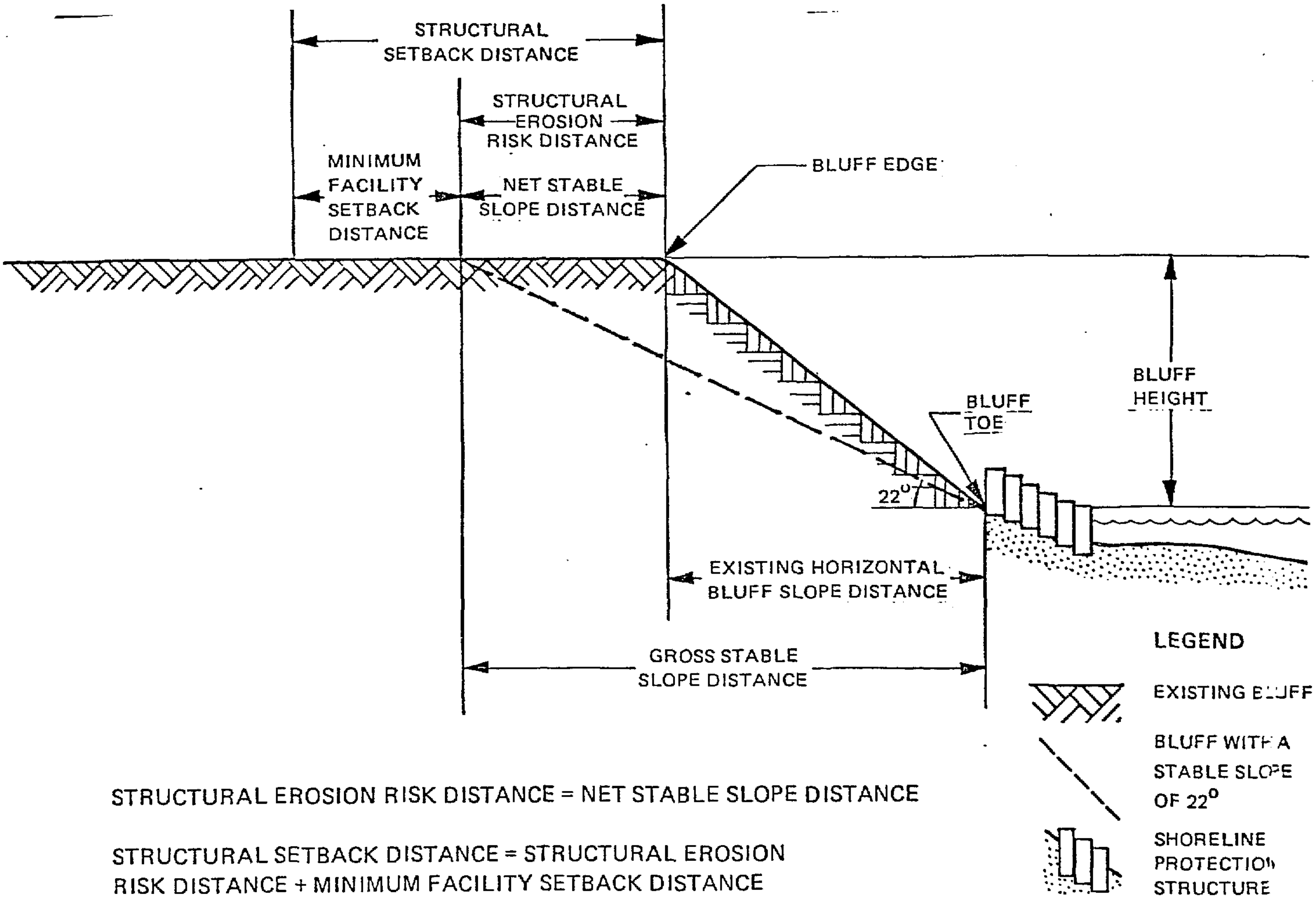
$$\text{GROSS STABLE SLOPE DISTANCE} = \frac{\text{BLUFF HEIGHT}}{\text{TAN } 22^{\circ}} = \frac{\text{BLUFF HEIGHT}}{0.4}$$

MINIMUM FACILITY SETBACK DISTANCE: TO BE DETERMINED BY LOCAL GOVERNMENTAL UNITS WITHIN THEIR AREA OF JURISDICTION TO PROVIDE A SAFETY FACTOR, FOR AESTHETICS, AND FOR PROVISION OF FUTURE SURFACE WATER AND GROUNDWATER DRAINAGE SYSTEMS

Source: SEWRPC.

Figure 30

PROCEDURE UTILIZED TO ESTIMATE STRUCTURAL EROSION RISK DISTANCE AND STRUCTURAL SETBACK DISTANCE



STRUCTURAL EROSION RISK DISTANCE = NET STABLE SLOPE DISTANCE

STRUCTURAL SETBACK DISTANCE = STRUCTURAL EROSION RISK DISTANCE + MINIMUM FACILITY SETBACK DISTANCE

WHERE: NET STABLE SLOPE DISTANCE = GROSS STABLE SLOPE DISTANCE - EXISTING HORIZONTAL BLUFF SLOPE DISTANCE

$$\text{GROSS STABLE SLOPE DISTANCE} = \frac{\text{BLUFF HEIGHT}}{\text{TAN } 22^{\circ}} = \frac{\text{BLUFF HEIGHT}}{0.4}$$

MINIMUM FACILITY SETBACK DISTANCE: TO BE DETERMINED BY LOCAL GOVERNMENTAL UNITS WITHIN THEIR AREA OF JURISDICTION TO PROVIDE A SAFETY FACTOR, FOR AESTHETICS, AND FOR PROVISION OF FUTURE SURFACE WATER AND GROUNDWATER DRAINAGE SYSTEMS

Source: SEWRPC.

The construction phase of urban development often results in excessive stormwater runoff, soil erosion, and sedimentation problems. After the construction phase is completed, stormwater runoff problems may become apparent because of changes made to the land surface. The following section describes criteria that may be used to help control construction site erosion and stormwater runoff impacts on shoreline erosion within the City of St. Francis study area. Because the entire study area is in proximity to the Lake Michigan shoreline, it is imperative that sound erosion control and stormwater management practices be adhered to, since any problems which develop will likely affect the shoreline.

Construction Site Erosion Control: Construction site erosion within the City of St. Francis study area is of particular concern, because increased amounts of stormwater runoff and sedimentation flowing over the top of the bluff and over the slope face itself could alter the shear strength of the materials within the bluffs, thereby reducing the stability of the bluff slopes. Provisions for controlling surface stormwater runoff and soil erosion during construction should be included within the initial plans for urban development. The following four major concerns should be addressed when developing construction site erosion control measures for shoreland development:

1. Construction activities should be carefully controlled and development restrictions applied where such construction could threaten the stability of the bluff slopes.

2. The rate and volume of stormwater runoff during construction should be controlled if there is a threat of significant increases in soil erosion and bluff recession, or if the stability of the bluff slopes is reduced.

3. Onsite erosion control measures should be implemented during the construction phase to reduce soil erosion by limiting the extent and duration of exposure of exposed soil surfaces.

4. Measures should be utilized to prevent the tracking or dropping of soil onto any public or private streets.

Stormwater Runoff Control: The rate and volume of stormwater runoff is influenced by the type of land use in the study area. Presently, the largest single land use within the City of St. Francis study area is unused urban land. The potential conversion of this open land from its naturally vegetated state to developed urban land uses, as well as other land use changes, would increase the proportion of impervious areas--roads and streets, parking lots, and rooftops--which would result in increased volumes of stormwater runoff and decreased runoff times for any given rainfall event. The following stormwater management shoreline erosion and bluff recession objectives should be addressed in development plans for the study area:

1. The stormwater drainage facilities should reduce the loss of real and personal property damage resulting from inadequate stormwater drainage and from stormwater runoff, both of which may increase the risk of bluff recession.

2. The stormwater drainage facilities should be designed to accommodate stormwater runoff from proposed land uses by considering the type of development and the topography of the land surface to be developed.

3. The stormwater drainage facilities should be designed to control soil erosion and sedimentation problems which may increase shoreline erosion and bluff recession.

4. The stormwater drainage facilities should be designed to prevent stormwater runoff-related damages to shoreline protection measures.

STRUCTURAL SHORE PROTECTION MEASURES

Based upon the inventory information set forth in Chapter II, alternative structural shore protection measures were developed and evaluated for the actively eroding shoreline in the study area. This chapter sets forth conceptual designs for and the estimated costs of alternative structural measures. More detailed and comprehensive data on the bathymetry and configuration of the near-shore area, groundwater drainage conditions, wave conditions, and bluff loading and soil characteristics are required for the actual engineering design of any structural measure. The type of structural measure selected is also dependent upon the intended use of the study area, and particularly the shoreline adjacent to the lake. The alternative structure designs and associated costs presented in this chapter are based upon structural design examples prepared for similar Lake Michigan shoreline areas.[3] The general designs and cost estimates represent structures with an expected economic life of 25 to 50 years. All costs are presented in 1984 dollars.

Complete shore protection within the study area will require a combination of bluff toe protection, bluff slope stabilization, and surface water and groundwater drainage control. Several measures are available to protect the toe of the bluff against the erosive forces of wave action and ice damage. Bluff slope stabilization is required to prevent the continued failure and subsequent recession of the unstable bluff slopes even after toe protection is provided and to help ensure that the toe protection measures remain structurally sound. Surface water drainage control is required to prevent significant amounts of surface water runoff from discharging over the top of the bluff. Such surface runoff could erode the regraded bluff slope and accumulate behind the bluff toe protection measures, resulting in a buildup of hydrostatic pressure which could damage the protection measures. Groundwater drainage control is required to abate excessive groundwater seepage from the bluff slopes which would threaten the stability of even a regraded bluff slope.

Bluff Toe Protection Measures

Alternative bluff toe protection measures evaluated for the St. Francis study area include rip-rap revetments, bulkheads, groins, and breakwaters. These structures protect the bluff toe either by providing an armor material at the toe to retain the bluff and prevent wave or ice erosion, or by extending the beach area to absorb the wave and ice energy before it reaches the bluff.

Rip-Rap Revetment: Revetments contain a flattened slope at the bluff toe armored with material resistant to wave erosion and ice damage, and underlaid by filter cloth and gravel bedstone. The armor layer would consist of natural

[3]See Owen Ayres & Associates, Great Lakes Shore Erosion Protection, Structural Design Examples, Wisconsin Coastal Management Program, August 1978.

rock rip-rap. The armor layer resists the wave and ice action and provides structural stability. The gravel bedstone and filter cloth support the armor layer against settlement, provide drainage through the revetment, and prevent underlying soil from being washed through the armor layers by waves or groundwater seepage. Toe protection would be provided to prevent lakeward displacement of the revetment caused by wave scouring. Flank protection would also be provided to prevent erosion at the ends of the revetment by tying the revetment to adjoining structures or to an adjacent stabilized bluff slope. The revetment would be designed similar to the revetment located just south of the Wisconsin Electric Power Company Lakeside power plant. Figure 31 shows a cross-section of the rip-rap revetment constructed by the Wisconsin Electric Power Company. The revetment would be placed along the entire shoreline within Bluff Analysis Sections 1 through 6.

The advantages of a rip-rap revetment are that it is relatively easy to construct and maintain; it is flexible; and it creates a relatively natural appearance to the shoreline. In addition, maintenance of a beach would be more likely with a revetment than with a bulkhead because a revetment causes less wave reflection and downcutting.

The primary disadvantage of a rip-rap revetment is that the structure generally makes human use of the immediate shoreline area difficult and access to the lake water may be precluded. A revetment is generally poorly suited for use for swimming, boating, and fishing, although recreational facilities such as walkways and piers may be incorporated into the design.

Construction of a rip-rap revetment along the Lake Michigan shoreline of the City of St. Francis similar to the revetment in place just south of the Lakeside power plant would require a capital cost of approximately $860 per linear foot of shoreline, or about $3.8 million for the entire actively eroding shoreline within the study area. Average annual maintenance costs for a revetment range from 1 to 2 percent of the capital cost.[4] Therefore, maintenance costs could range up to about $80,000 per year. It should be noted that depending upon the type and location of development to be protected, the revetment could be designed for a somewhat smaller level of protection, at a potential reduction in cost of up to 50 percent.

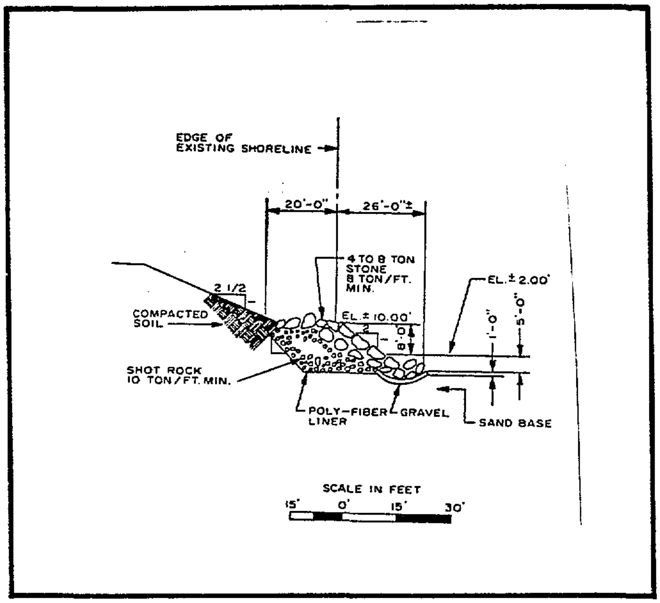
Bulkhead: Bulkheads are retaining walls usually constructed of concrete, steel sheet piling, or timber which support the base of the bluff and provide protection against wave and ice action. Three alternative bulkhead designs were evaluated for the study area: a concrete cantilevered bulkhead, a steel sheet piling bulkhead, and a concrete-stepped bulkhead.

Concrete Cantilevered Bulkhead--A cantilevered, cast-in-place-reinforced concrete bulkhead, as illustrated in Figure 32, would be constructed to both retain the bluff toe and provide protection against wave and ice action. The bulkhead would consist of a concrete base with a cantilevered wall. The wall would be constructed with weep holes and backfilled with sufficient coarse granular material to prevent hydrostatic pressure buildup and frost heave. In addition, a continuous sheet pile or concrete wall would be placed below the base of the

[4]J. Philip Keillor, Coastal Engineer, University of Wisconsin-Sea Grant Program, Personal Communication, July 1984.

Figure 31

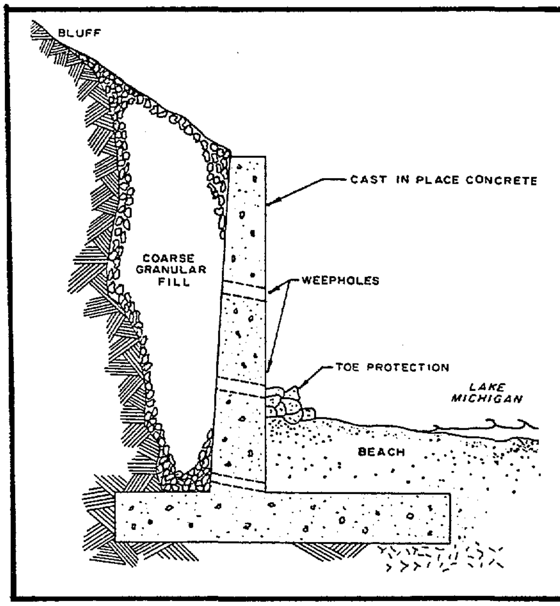
RIP-RAP REVETMENT AS CONSTRUCTED JUST SOUTH OF THE WISCONSIN ELECTRIC POWER COMPANY LAKESIDE POWER PLANT



Source: Wisconsin Electric Power Company.

Figure 32

CONCRETE CANTILEVERED BULKHEAD



Source: Owen Ayres & Associates, Great Lakes Shore Erosion Protection, Structural Design Examples, 1978.

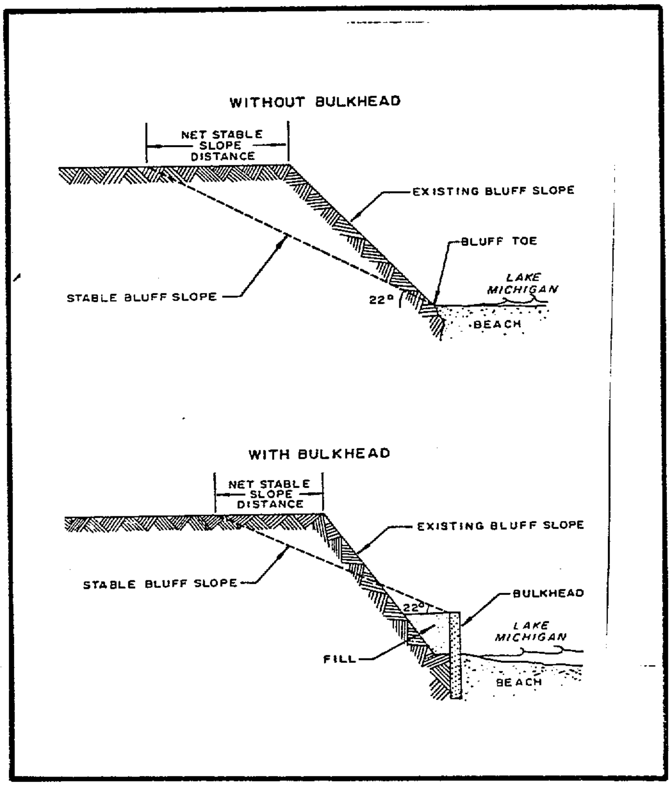
structure and tied into the base slab to prevent undermining during low-water-level conditions. Rip-rap toe protection would also be provided. A cantilevered bulkhead derives its support solely from ground penetration, so sufficient embedment is required. A cantilevered bulkhead could be placed along the entire shoreline within Bluff Analysis Sections 1 through 6.

A primary advantage of a cantilevered bulkhead, as well as other bulkheads, is that the structure can be constructed to a height of 10 to 15 feet above the existing beach and can be placed lakeward of the existing bluff toe. Fill would be placed behind the bulkhead and the bluff slope could be regraded from the top of the bulkhead, rather than from the existing bluff toe. This would effectively reduce the required bluff toe regrading distance to achieve a stable bluff slope, as shown in Figure 33. Thus, these stable slope distances could be significantly reduced if a bulkhead was constructed. Another advantage of a bulkhead is that it provides a uniform appearance and may be suited for recreational facilities such as walkways, piers, and boat slips which may enhance the use of the shoreline. The construction of a cantilevered bulkhead would not require special heavy-duty or pile-driving equipment.

A disadvantage of a bulkhead is that the structure is relatively inflexible, and maintenance, when required, is fairly difficult and expensive. If a high bulkhead is constructed, direct access to the lake water could be difficult, and uses such as swimming would be precluded. A bulkhead also reflects the waves, causing downcutting, and it is likely that the existing beach areas would be eroded by the wave action.

Figure 33

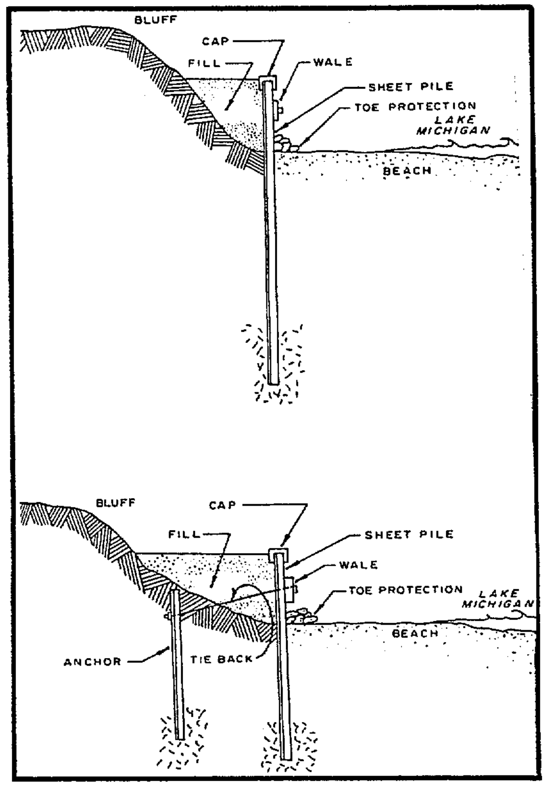
EFFECT OF A BULKHEAD ON THE BLUFF TOP REGARDING DISTANCE REQUIRED TO ACHIEVE A STABLE BLUFF SLOPE



Source: SEWRPC.

Figure 34

ALTERNATIVE STEEL SHEET PILING BULKHEAD DESIGNS



Source: U. S. Army Corps of Engineers, Low Cost Shore Protection...A Guide for Engineers and Contractors, 1981.

Construction of a concrete cantilevered bulkhead along the Lake Michigan shoreline of the City of St. Francis would require a capital cost of approximately $400 per linear foot of shoreline, or about $1.8 million for the entire actively eroding shoreline within the study area. Average annual maintenance costs are assumed to range up to 2 percent of the capital cost, or $35,000.

Steel Sheet Piling Bulkhead--A steel sheet piling bulkhead, as shown in Figure 34, would provide the same type of protection provided by a concrete cantilevered bulkhead. The structure would be deeply embedded beneath the beach surface, and would include the construction of a piling with adequate walers to provide rigidity. As an alternative design, the sheet piling could also be anchored with tie backs, as also shown in Figure 34. Rip-rap toe protection and weep holes for drainage would also be provided. The structure would be backfilled with coarse granular material. A steel sheet piling bulkhead could be placed along the entire shoreline within Bluff Analysis Sections 1 through 6.

A steel sheet piling bulkhead has advantages and disadvantages similar to those described above for concrete cantilevered bulkheads. However, special pile-driving equipment is required to install the structure. Construction of a steel sheet piling bulkhead along the Lake Michigan shoreline of the City of St. Francis would require a capital cost of approximately $630 per linear foot of shoreline, or about $2.8 million for the entire actively eroding shoreline within the study area. Average annual maintenance costs are assumed to range up to 2 percent of the capital cost, or about $60,000.

Concrete-Stepped Bulkhead--A third alternative bulkhead design involves construction of a massive, cast-in-place, concrete-stepped bulkhead, as shown in Figure 35. The bulkhead, cast as a massive, gravity-held structure to resist overturning by wave action or soil pressures, would include a splash apron along the crest of the bulkhead to prevent erosion from overtopping, and rip-rap toe protection. As shown in the figure, the face of the bulkhead would be stepped toward the lake. A concrete-stepped bulkhead could be placed along the entire shoreline within Bluff Analysis Sections 1 through 6.

A concrete-stepped bulkhead would have the same advantages as a concrete cantilevered bulkhead regarding reduced stable slope distance, uniform appearance, and suitability for recreational facilities. In addition, a concrete-stepped bulkhead would not require deep embedment or piles beneath the beach, and the steps would provide access to the lake water. The structure would therefore be more suitable for uses such as swimming and fishing than would a revetment or other types of bulkheads. In addition, concrete-stepped bulkhead would probably have fewer maintenance needs.

The disadvantages described above for a concrete cantilevered bulkhead concerning structure inflexibility and accelerated beach erosion would also apply to a concrete-stepped bulkhead, although the beach erosion would not be as severe because the face of the bulkhead is not vertical, resulting in less downcutting.

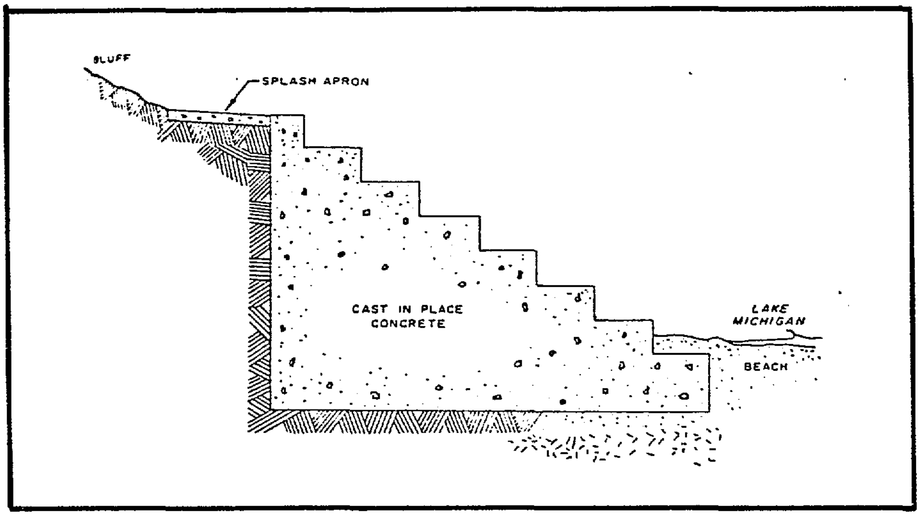
Construction of a concrete-stepped bulkhead along the Lake Michigan shoreline of the City of St. Francis would require a capital cost of approximately $1,140 per linear foot of shoreline, or about $5.1 million for the entire actively eroding shoreline within the study area. Average annual maintenance costs are assumed to range up to 1 percent of the capital cost, or about $50,000.

Groins: Groins are connected to and constructed perpendicular to the shoreline and are intended to partially obstruct the longshore current which results in the accumulation of sand up-current of the structure. A series of groins can trap enough sand to build an artificial beach which absorbs wave energy and protects the bluff toe. However, the Lake Michigan longshore current is interrupted by the Milwaukee South Shore breakwater, and insufficient sand is available to maintain an artificial beach. Therefore, groins would not be an effective means of building and maintaining a sand beach in the study area.

However, groins could be used to maintain an artificially filled gravel-cobble beach in Bluff Analysis Section 6. Section 6 is protected by the Milwaukee South Shore breakwater, and the breakwater should sufficiently reduce wave energy so that a beach composed of relatively large--up to 10 inches in diameter--beach material could be maintained with the use of relatively short groins. The groins, as shown in Figure 36, would be constructed of limestone slabs and would be connected to the existing bluff toe and extend from the

Figure 35

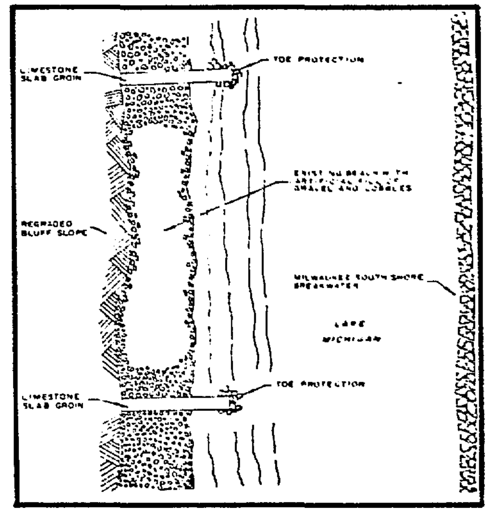
CONCRETE STEPPED BULKHEAD



Source: Owen Ayres & Associates, Great Lakes Shore Erosion Protection, Structural Design Examples, 1978.

Figure 36

GROIN SYSTEM WITH ARTIFICIAL BEACH FILL OF GRAVEL AND COBBLES FOR BLUFF ANALYSIS SECTION 6



Source: SEWRPC.

beach area into the lake. Rip-rap toe protection would be provided at the lakeward end of the groins. The groins would be of sufficient height to prevent flanking and excessive overtopping. The area between the groins would be filled with well-graded material--primarily gravel and cobbles. Some sand would also likely be trapped by the groins. Periodic replenishment of the beach material may be required.

The primary advantage of a groin system artificially filled with gravel and cobbles in Bluff Analysis Section 6 is that an extended beach would be provided to protect the bluff toe against wave action and to allow access to the lake for walking, swimming, fishing, and boating. Detailed wave analyses would be required to determine whether additional structures would be needed to prevent further bluff toe erosion.

The disadvantages of a groin system are that considerable maintenance could be required to keep the extended beach intact, and insufficient bluff toe protection may be provided by the beach during large storm events. Furthermore, the Wisconsin Department of Natural Resources currently prohibits artificial beach nourishment with sand. The Department would have to approve the filling of the groin spaces with gravel and cobbles.

The construction of a series of limestone slab groins and an artificial gravel-cobble beach in Bluff Analysis Section 6 would require a capital cost of approximately $125 per linear foot of shoreline, or approximately $200,000 for Section 6. Annual maintenance costs are estimated at $5,000.

Breakwater: Breakwaters are protective structures built out from, and generally parallel to, the shore. They provide dissipation of deep-water wave energy. A description of the Milwaukee South Shore breakwater, which protects the northern part of the study area, is presented in Chapter II. As noted in Chapter II, the breakwater has deteriorated significantly since its construction in 1930 and 1931. It has been estimated that a significant amount--perhaps half--of the wave energy that reaches the breakwater overtops the structure and reaches the shoreline.[5] Since maintenance of the breakwater is the responsibility of Milwaukee County, repair of the structure would have to be conducted cooperatively with the County.

The advantages of repairing the existing Milwaukee South Shore breakwater are that the breakwater would serve to provide some additional protection of the eroding bluff toe in Bluff Analysis Section 6 and further enhance the development of a beach. Repair of the breakwater would be more economical than constructing a new breakwater. Also, breakwaters do not interfere with any recreational shoreline uses.

A disadvantage of repairing the existing breakwater is that heavy equipment mounted on barges would be required for the installation and continued maintenance. Furthermore, even with reconstruction of the breakwater, additional bluff toe protection measures and beach stabilization measures may be required to adequately protect Bluff Analysis Section 6. Since maintenance of the breakwater is the responsibility of Milwaukee County, repair of the structure would have to be coordinated, and conducted cooperatively, with the County.

Reconstruction of the entire 9,350-foot-long Milwaukee South Shore breakwater would require a capital cost of approximately $13.2 million. Annual maintenance costs following reconstruction could range up to 2 percent of the capital cost, or $260,000. Reconstruction of only the 4,600-foot-long section of the breakwater which protects a portion of the study area would require a capital cost of approximately $6.5 million, and an annual maintenance cost of about $130,000.

Other Bluff Toe Protection Measures: Bluff toe protection could also be provided by gabions, interlocking concrete block revetments, longard tubes, and Beachbuilders of America, Inc., sand interceptors. Gabions, or rock-filled wire baskets, could be used to construct revetments or groins. They are flexible and can be relatively easy to construct and maintain. The gabions, however, may not withstand the wave energy and ice action present along an unprotected Lake Michigan shoreline.

Revetments could be constructed of interlocking concrete blocks, of which several types are available commercially. The revetment would be constructed with a line of piling at its toe to hold the concrete blocks in place. The blocks would be placed on a gravel layer which overlies a filter cloth. However, interlocking concrete blocks tend to be relatively inflexible structures and may be susceptible to frost heave at the water line.

[5]J. Philip Keillor, Coastal Engineer, University of Wisconsin-Sea Grant Program, Letter to Earl K. Anderson, Harbor Engineer, Port of Milwaukee, September 14, 1983.

A longard tube is a woven, polyethylene tube available in 40- and 69-inch diameters. The tubes are filled with sand at the installation site and can be used to construct revetments or groins. The tubes, however, are vulnerable to damage by vandals and by waterborne debris.

Beachbuilder sand interceptors are flexible, plastic strips which are anchored into the bottom of the lake just off shore. The undulating strips trap sand particles which can create an artificial beach, similar to the effect of a groin system. The beach would provide some protection against wave action at the bluff toe. The Beachbuilder system is easy to install and has a relatively low cost. This system, however, would not likely be an effective alternative for the study area because little sand is transported in the longshore current due to the effects of the Milwaukee South Shore breakwater.

Bluff Slope Stabilization

Alternative bluff slope stabilization methods evaluated for the St. Francis study area include the cutback method and the terracing method. Both methods involve cutting back the existing bluff slope to provide slope stability.

Cutback Method: Bluff slope stabilization can be accomplished by using earth-moving equipment to regrade the face of the slope to a flatter, more stable profile, as shown in Figure 33. As previously discussed, it has been determined that a bluff slope of one on two and one-half would be required to provide stable bluff slopes in the study area. Regrading the bluff slopes to this stable angle would require cutting and removing about 229,000 cubic yards of bluff material, as set forth in Table 12, if bluff toe protection was to be provided without a bulkhead. If a bulkhead was to be used to provide toe protection, the amount of bluff material removed could be reduced by 41 percent, to 137,000 cubic yards. Topsoil placement, seeding, and mulching would be required to develop a protective vegetative cover. Bluffs would need to be stabilized within Bluff Analysis Sections 1 through 6.

Table 12

AMOUNT OF BLUFF MATERIAL AND BLUFF TOP AREA REQUIRED TO BE CUT AND REMOVED TO PROVIDE A STABLE SLOPE OF ONE ON TWO AND ONE-HALF

Bluff Analysis Section	Bluff Toe Protection With a Bulkhead[a]		Bluff Toe Protection Without a Bulkhead[a]	
	Material Amount (cubic yards)	Bluff Top Area (acres)	Material Amount (cubic yards)	Bluff Top Area (acres)
1	50,700	1.07	69,400	1.40
2	28,800	0.84	44,000	1.40
3	4,300	0.28	8,300	0.39
4	15,500	0.53	26,500	0.75
5	25,400	1.50	51,800	2.22
6	12,400	0.52	29,200	1.01
Total	137,000	4.74	229,000	7.17

[a]For the purpose of these calculations, the top of the bulkhead is assumed to be 10 feet above the base of the bluff.

Source: SEWRPC.

A primary advantage of bluff slope stabilization is that further bluff recession would be prevented--provided that bluff toe protection and surface and groundwater drainage would be provided where needed. Slope stabilization would also provide structural stability to the bluff toe protection measures, preventing them from being buried by bluff material, and from erosion from behind the structure.

The disadvantage of bluff slope stabilization is that approximately 7.2 acres of land at the top of the bluff would be needed for the bluff regrading if bluff toe protection was to be provided by a structure other than a bulkhead. If a bulkhead was to be used to provide toe protection, the land at the top of the bluff needed for regrading would be reduced to 4.7 acres, as indicated in Table 12.

Assuming bluff toe protection is provided by a bulkhead, slope stabilization--including excavation, hauling of excess material, regrading, and vegetating the slope--would require an average capital cost of approximately $107 per linear foot of shoreline, or about $430,000 for the entire actively eroding shoreline within the study area. Assuming bluff toe protection is provided by a structure other than a bulkhead, slope stabilization would require an average capital cost of approximately $152 per linear foot of shoreline, or about $610,000 for the entire actively eroding shoreline within the study area. Maintenance costs are assumed to be about $5,000 per year with or without a bulkhead.

Terracing Method: Slope stabilization can also be provided by the placement of a series of retaining walls within the regraded bluff slope, as shown in Figure 37. The retaining walls would be constructed of stone, interlocking concrete blocks, steel sheet pile, or gabions. The bluff slope between the retaining walls would be regraded to one on two and one-half or flatter and vegetated.

The terracing method has the same advantages regarding slope stabilization and support of bluff toe protection structures described above for the cutback method. In addition, the terracing method could provide improved access to the shoreline if a suitable walkway were provided. Depending upon the design of the terrace system, less bluff material may need to be removed than under the cutback method, which would reduce the net stable slope distance.

The primary disadvantage of the terracing method is its relatively high cost. Construction of a terraced bluff slope would require a capital cost of approximately $2,400 per linear foot of shoreline, or about $10.7 million for the entire actively eroding shoreline in the study area. Maintenance costs would be approximately $10,000 per year.

Surface Water Drainage Control

Almost the entire study area drains toward Lake Michigan over the top of the bluffs. Uncontrolled storm runoff could erode gullies on the regraded bluff slopes and cause erosion or create excessive hydrostatic pressures behind the bluff toe protection measures. Increased surface runoff would result from the increase in impervious areas that would result from development of the study area. This surface runoff should be prevented from flowing over the top of the bluff.

If the study area is developed, the attendant stormwater drainage facilities could divert the storm runoff westward toward S. Lake Drive, thereby preventing flow over the bluff top. The drainage facilities would be designed to accommodate anticipated peak flow discharges from a 10-year recurrence interval flood event and to prevent flooding and ponding which could cause excessive seepage or add weight to the bluff.

As an alternative, stormwater diversion channels would be constructed parallel to the bluff top in Bluff Analysis Sections 1 through 6, as shown in Figure 38. The grassed open channels would intercept stormwater runoff, preventing flow over the bluff top. A subsurface pipe or a stabilized channel would discharge the intercepted runoff to the toe of the bluff. The open channels and discharge pipes would be designed to accommodate anticipated peak flow discharges from a 10-year recurrence interval storm event.

The construction of diversion channels and discharge pipes would require a capital cost of about $10 per linear foot of shoreline, or approximately $40,000 for the entire actively eroding shoreline within the study area. Maintenance costs would be approximately $2,000 per year.

Groundwater Drainage Control

There is evidence, or actual observations have been made, of groundwater seepage from the bluff face in Bluff Analysis Sections 1, 3, 4, and 6. Detailed geotechnical studies should be conducted to determine subsurface stratigraphy and groundwater conditions west of the bluff edge. This detailed information could be used to design a groundwater drainage system for the study area. Based on the groundwater conditions and stratigraphy identified at the bluff face, however, the seepage observed in Bluff Analysis Sections 1 and 6 is not expected to prevent stable bluffs from forming at a regraded slope of one on two and one-half. Within Sections 3 and 4, groundwater drainage control would be expected to enhance slope stability.

The groundwater seepage which occurs at the present time within Sections 3 and 4 would be abated by the installation of a vertical well system, as shown in Figure 39. The vertical well system would pump water to the bluff toe surface and discharge the water either at the bluff toe with an outlet pipe, as shown in the figure, or into the surface water drainage system. The well system would drain the groundwater table down to the beach elevation. Detailed geotechnical analyses would be used to determine the necessary location, depth, and pumping rate of the well points.

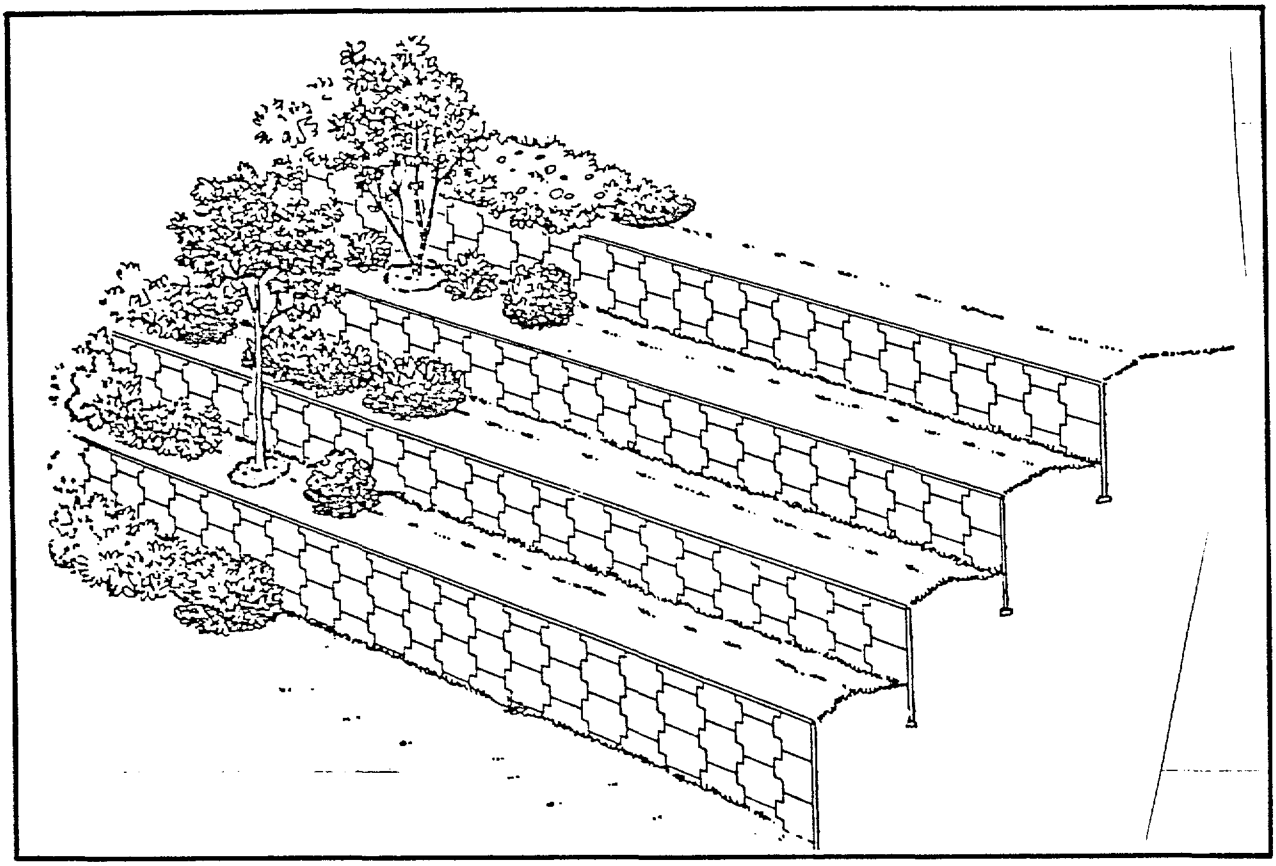
Construction of a vertical well system to abate groundwater seepage within the 600-foot-long shoreline of Bluff Analysis Sections 3 and 4 would require a capital cost of approximately $30 per linear foot of shoreline, or about $20,000 for both sections. The annual operation and maintenance cost would be approximately $1,000.

EROSION RISK DISTANCES AND SETBACK DISTANCES CONSIDERING NONSTRUCTURAL AND STRUCTURAL SHORE PROTECTION MEASURES

Nonstructural and structural shoreline erosion risk distances and facility setback distances are herein identified for the City of St. Francis study area. The nonstructural erosion risk distances represent the shoreland areas that

Figure 37

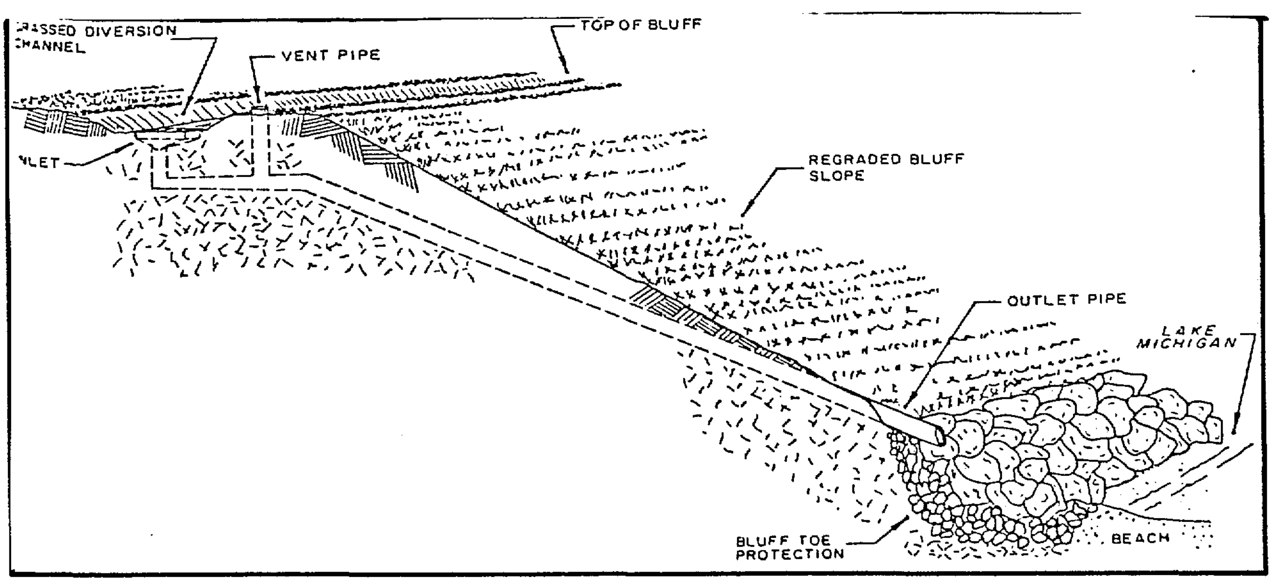
TERRACED BLUFF SLOPE STABILIZATION METHOD



Source: D. H. Gray and A. T. Leiser, Biotechnical Slope Protection and Erosion Control, 1982.

Figure 38

STORMWATER DRAINAGE SYSTEM TO PREVENT EXCESSIVE STORM RUNOFF OVER THE TOP OF THE BLUFF

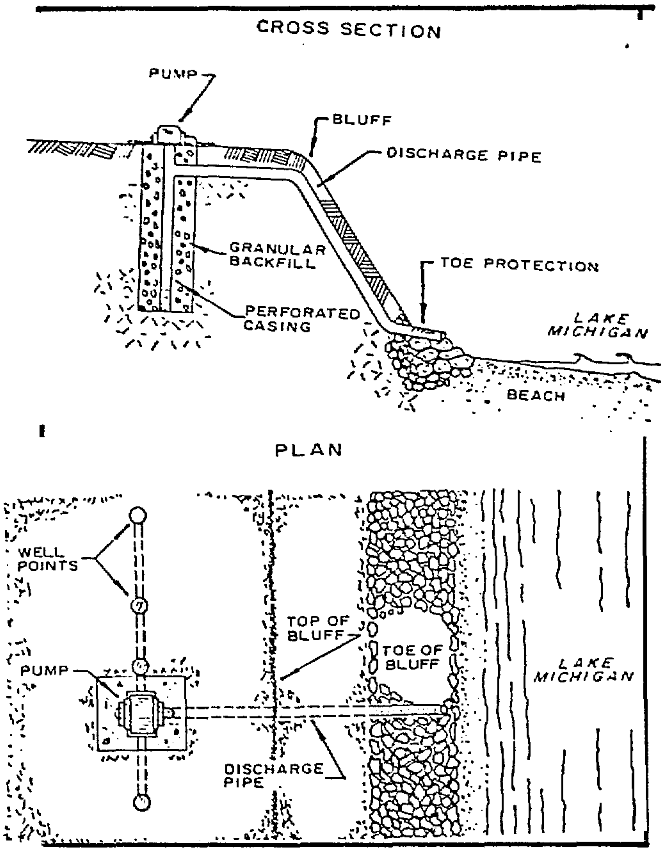


Source: SEWRPC.

may be expected to be affected by shoreline erosion and bluff recession over time if proper shore protection structures are not implemented. Shore protective structures could, however, be installed to substantially reduce land losses within the City's actively eroding bluff areas. The structural erosion risk distance represents the areas which may be affected by bluff recession if proper protection structures are installed. Minimum facility setback distances have been added to both the nonstructural and structural erosion risk distances as a safety factor for new urban development.

Figure 39

VERTICAL WELL SYSTEM FOR GROUNDWATER DRAINAGE AND SEEPAGE CONTROL



Source: Owen Ayres & Associates, Great Lakes Shore Erosion Protection, Structural Design Examples, 1978.

Table 13 indicates, for each bluff recession reach, the distance the top of the bluff may be expected to recede over a 50-year period if structural shore protection measures are not implemented. These distances were determined by multiplying the average annual recession rates established for the period 1963 through 1980 by 50 years. The table also indicates the gross stable slope distances, or the horizontal distances, required to obtain a stable slope for the specified bluff heights, assuming a slope of one on two and one-half. Since most bluff slopes are not vertical, the existing horizontal distance of the bluff slope was subtracted from the gross horizontal stable slope distance to estimate the net stable slope distance--or the additional horizontal distance the top of the bluff would need to recede, or be regraded, to form a stable slope. In Table 13, the bluff recession distance--determined from historic measured rates of recession--and the net stable slope distance are added to establish the nonstructural erosion risk distance for a 50-year period of time.

The structural erosion setback distances shown in Table 13 were determined by adding the distance required to form a stable slope of one on two and one-half to the amount of bluff recession expected to occur over the next five years, which was assumed to be a likely time period for the implementation of structural bluff toe protection measures. The bluff recession estimated during the five-year implementation period was calculated using the average annual recession rates established for the period 1963 through 1980. Once the installation of the structures is completed, the rate of bluff recession is assumed to be zero.

Table 13

NONSTRUCTURAL AND STRUCTURAL EROSION RISK DISTANCES AND SETBACK DISTANCES WITHIN THE ACTIVELY ERODING PORTIONS OF THE CITY OF ST. FRANCIS LAKE MICHIGAN SHORELINE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Estimated Bluff Recession Distance (feet)			Gross Horizontal Stable Slope Distance (feet)			Net Horizontal Stable Slope Distance (feet)		Erosion Risk Distances (feet)			Nonstructural Setback Distances (feet)		Structural Setback Distances (feet)	
										Structural					
Bluff Recession Reach	5-Year[a]	50-Year[b]	Existing Bluff Height (feet)	Without Bulkhead	With Bulkhead	Existing Horizontal Slope Distance (feet)	Without Bulkhead[c] (5-7)	With Bulkhead[d] (6-7)	50-Year Nonstructural (3 + 8)	Without Bulkhead[c] (2 + 8)	With Bulkhead[d] (2 + 9)	Public Utilities and Public Recreation Facilities (10 + 100 feet)	All Other Facilities and Buildings (10 + 200 feet)	Without Bulkhead[c] (11 + 100 feet)	With Bulkhead[d] (12 + 100 feet)
1	28	280	68	170	143	68	102	75	382	130	103	482	582	230	203
2	25	250	68	170	143	65	105	78	355	130	103	455	555	230	203
3	24	240	58	145	118	52	93	66	333	117	90	433	533	217	190
4	16	165	52	130	103	65	65	38	230	81	54	330	430	181	154
5	14	135	52	130	103	68	62	35	197	76	49	297	397	176	149
6	24	235	50	125	98	69	56	29	291	80	53	391	491	180	153
7	10	100	50	125	98	55	70	43	170	80	53	270	370	180	153
8	12	120	50	125	98	65	60	33	180	72	45	280	380	172	145
9	18	185	46	115	88	52	63	36	248	81	54	348	448	181	154
10	16	160	44	110	83	65	45	18	205	61	34	305	405	161	114
11	20	205	44	110	83	61	49	22	254	69	42	354	454	169	142
12	16	160	42	105	78	48	57	30	217	73	46	317	413	173	146
13	10	100	42	105	78	52	53	26	153	63	36	253	353	163	136
14	1	10	50	125	98	81	44	17	54	45	18	154	254	145	118
15	2	25	42	105	78	75	30	3	55	32	5	155	255	132	105
16	2	15	40	100	73	82	18	0	33	20	2	133	233	120	102
17	10	100	40	100	73	61	39	12	139	49	22	239	339	149	122
18	4	40	42	105	78	100	5	0	45	9	4	145	245	109	104
19	14	140	38	95	68	90	5	0	165	39	14	265	365	139	114

[a] In determining structural erosion setback distances, a period of five years was used as an estimate of the time period required to implement shore protection structures.

[b] The nonstructural erosion risk distances are for a period of 50 years.

[c] Asumes bluff toe protection with a structure other than a bulkhead. The nonstructural alternative assumes no bluff toe protection.

[d] Assumes bluff toe protection with a 10-foot-high bulkhead placed two feet lakeward from the existing bluff toe.

Source: SEWRPC.

Also shown in Table 13 are the setback distances for new urban development identified under the nonstructural and structural shore protection alternatives. Those distances were determined by adding recommended minimum facility setback distances to the erosion risk distances. For the nonstructural setback distance, a minimum facility setback distance of 100 feet is recommended for public utilities and public recreation facilities, and a 200-foot minimum facility setback distance is recommended for all other permanent buildings and facilities. A 200-foot minimum facility setback distance is recommended for these buildings and facilities to provide an additional safety factor because future bluff recession rates could differ substantially from the historic bluff recession rates. These minimum facility setback distances would provide a conservative safety factor; would allow installation of surface water and groundwater drainage systems if needed; would maintain desired aesthetics near the bluff edge; and would not reduce the stability of the bluff slopes.

The stable slope distances and structural erosion risk and setback distances are set forth in Table 13 assuming bluff toe protection with a bulkhead, and assuming bluff toe protection without a bulkhead. As previously discussed, installation of a bulkhead could reduce the stable slope distance and the resulting structural erosion risk and setback distances because the bluff slope would have to be regraded from only the top of the bulkhead in order to form a stable slope.

Areas within the nonstructural and structural erosion risk distances and setback distances are shown on 1 inch equals 400 feet scale topographic maps in Appendices C and D. The nonstructural maps in Appendix C show, for the entire city shoreline, the 50-year erosion risk distances, which indicate the future bluff edge location if no additional shore protection structures are implemented, and the 100- and 200-foot-wide setback distances based on the anticipated location of the bluff edge after 50 years. The structural maps in Appendix D show the erosion risk distances with bluff toe protection both with and without a bulkhead. Also provided on the structural maps are the 100-foot-wide minimum facility setback distances based on the location of the bluff with shore protection structures. Finally, the bluff recession reaches for the actively eroding bluff areas are shown on the maps so that the user can determine the average annual bluff recession rate for any site.

The land areas contained within the 50-year nonstructural and structural erosion risk distances, as delineated in Appendices C and D, are set forth in Table 14. Approximately 20 acres of land, or about 12 percent of the City of St. Francis study area, lie within the 50-year nonstructural erosion risk distances. About five acres of land, or about 3 percent of the study area, lie within the erosion risk distances assuming structural shore protection with a bulkhead for bluff toe protection. About seven acres of land, or about 4 percent of the study area, lie within the erosion risk distances assuming structural shore protection with bluff toe protection provided by a structure other than a bulkhead.

The potential economic losses that would result from continued bluff recession may be estimated by determining the market value of the land located within the erosion risk areas. The 1983 value of land contained within the 50-year nonstructural erosion risk distances--based on city tax assessments--is approximately $650,000. If bluff protection were to be provided by a bulkhead, the land within the structural erosion risk distance would have an approximate

Table 14

EXTENT AND ECONOMIC VALUE OF LAND AREA LYING WITHIN THE 50-YEAR NONSTRUCTURAL AND STRUCTURAL EROSION RISK DISTANCES FROM THE LAKE MICHIGAN SHORELINE OF THE CITY OF ST. FRANCIS

Erosion Risk Distance	Areal Extent (acres)	Percent of Study Area	Economic Value (dollars)[a]	Percent of Total Economic Value of Study Area
50-Year Nonstructural....	19.7	12.2	650,000	24.6
Structural Without Bulkhead[b]......	7.1	4.4	230,000	8.9
Structural With Bulkhead[c].........	4.7	2.9	160,000	5.9

[a]Excludes the existing Wisconsin Electric Power Company Lakeside power plant site.

[b]Assumes bluff toe protection by a structure other than a bulkhead.

[c]Assumes bluff toe protection with a 10-foot-high bulkhead.

Source: SEWRPC.

economic value of $160,000. If bluff toe protection were to be provided by a structure other than a bulkhead, the land within the structural erosion risk distance would have a value of about $230,000. These estimates exclude the value of land contained within the existing Lakeside power plant site. Of course, development of the study area could significantly change the economic value of the property.

LAND USE MANAGEMENT

The inventory data, analyses, and alternative shore protection evaluations set forth in this report provide a valuable reference for officials and residents of the City of St. Francis, as well as the owners of the study area property. The report sets forth the distance from the existing bluff edge that is subject to a risk of erosion damages along the Lake Michigan shoreline, and describes what actions can be taken to reduce that risk. Affected parties can thus act more judiciously and responsibly of their own accord in making decisions concerning development and redevelopment of the study area. It is crucial that affected parties be fully cognizant of the problems and hazards associated with shoreline development.

The information provided in this report will be helpful to all affected parties in addressing issues such as: the appropriate use of shoreland areas within the erosion risk distances; appropriate building setbacks; and the need for structural shore protection measures. The projections made herein of erosion and bluff recession should not be regarded as a potential threat to real property values, such values being related to existing and potential uses of the shoreland areas. Rather, it should be recognized that the natural characteristics and forces within the study area may conflict with certain potential uses of the land. It is a responsible course of action and in the long-term public interest to openly and extensively publicize the risks associated with bluff recession and the required control measures.

The City of St. Francis currently has a zoning ordinance which regulates land uses. This ordinance can be made more effective by adding provisions directly related to the erosion hazards which threaten the Lake Michigan shoreline. A zoning ordinance constitutes one viable tool for protecting new development and redevelopment within the study area.

Regulations can be developed which protect proposed development from excessive shoreline erosion and bluff recession by identifying the distance from the existing bluff edge that is subject to erosion risk, and by specifying a setback distance which restricts or prohibits the location of buildings and other land uses which are vulnerable to damages or destruction from erosion. These regulations can be readily incorporated into the existing city zoning ordinance, which regulates the use of land, the area and dimensions of lots, and the location of buildings and facilities on such lots. Zoning can also control grading, filling, vegetation removal, and certain other land management practices. To be constitutionally valid, however, regulation of the land use within the setback distances must serve valid public objectives, leave the property owner with some reasonable use of his property, and provide sufficient standards to prevent arbitrary decision-making. In addition, there must be a reasonable property owner with some reasonable use of his property, and provide sufficient standards to prevent arbitrary decision-making.

Amendments to the City of St. Francis zoning ordinance could, in the public interest, regulate land uses, activities, and facility locations within the specified setback distances. The amendments would include provisions defining pertinent terms, designating the lands to be regulated, specifying the necessary regulation of land use and facility location, specifying the regulation of certain land disturbance activities, and describing procedures for modifying the location and extent of the designated setback distances. The Regional Planning Commission would, upon request, assist the City in incorporating into the zoning ordinance provisions related to erosion risk and associated setback distances along the Lake Michigan shoreline of the City of St. Francis.

As an alternative to amending the City's zoning ordinance, the information on setback distances could instead be presented as advisory recommendations to potential land developers. The City would not need to administer and enforce these land use regulations; rather, the City's role would be to communicate this information adequately to potential land developers and to help coordinate implementation efforts. Adequate compliance with the recommendations, however, would not be assured without a regulatory program.

Of particular concern regarding land use management in the study area are those activities related to urban land under construction and to stormwater management. Construction site erosion control and stormwater management criteria have been set forth in this chapter. This section describes general land management measures which could be used to meet these criteria and thereby assure that shoreline erosion would not be accelerated by construction or by uncontrolled stormwater runoff during and following development.

The following provisions would aid in controlling soil erosion and excessive stormwater runoff within the study area during construction of urban development:

1. Development within the study area would be limited to outside the identified structural or nonstructural setback distances.

2. Plans for development would be prepared on 1 inch equals 100 feet scale topographic maps to be provided on request under this study to identify the existing ground surface; to identify areas with steep slopes; to propose and estimate street grades and profiles; to aid in the design of gutters, storm sewers, open drainage channels, water diversions, drainage easements, and soil erosion control practices; and to show the type and location of shoreline erosion control measures.

3. Plans for development would indicate the suitability of soils for development and identify areas covered by highly erodible soils.

4. Provisions would be made to effectively accommodate the stormwater runoff under the changed soil and surface conditions during construction which may aggravate shoreline erosion problems.

5. During construction, the smallest practicable area of soil would be exposed at any given time.

6. Such soil exposure during construction would be kept to as short a duration of time as is practicable.

7. Temporary vegetation, mulching, or other cover would be used to protect critical areas, and permanent vegetation would be installed as soon as practicable.

8. Adequate provisions would be taken to minimize the tracking or dropping of dirt or other materials from the site onto any public or private street.

The following provisions would aid in controlling stormwater runoff within the study area following completion of the development:

1. Stormwater drainage systems would consist of both a "minor" system and a "major" system. The minor stormwater drainage system would consist of engineered paths for the stormwater runoff during a more frequent storm event--one with a recurrence interval of up to 10 years. Minor stormwater drainage components include storm sewers and drainage ditches.

   The major stormwater drainage system would be designed for conveyance of stormwater runoff during a very infrequent storm event--one with a recurrence interval of up to 100 years. Major stormwater drainage components include streets and drainageways.

2. Provisions would be made to prevent surface stormwater runoff from being discharged uncontrolled over the top of the bluff, and to prevent runoff from damaging bluff toe protection measures by eroding soil behind the structures or by creating excessive hydrostatic pressures behind the structures.

3. The stormwater drainage systems would be carefully adjusted to the topography of the land in order to minimize grading and drainage problems, although modifications may be needed to prevent surface stormwater runoff from being discharged over the top of the bluff.

4. Provisions would be made to effectively accommodate the increased peak flows and volumes of stormwater runoff resulting from the addition of impervious surfaces to the study area.

5. Stormwater storage measures such as detention ponds and parking lot or rooftop storage devices--which could cause increased infiltration and groundwater seepage and add excessive weight too close to the top of the bluff--would not be utilized if such measures could threaten the stability of the bluff slope.

SUMMARY

This chapter evaluates the shoreline erosion and bluff recession occurring within the study area and considers alternative structural and nonstructural methods of controlling, or reducing the damages from, such erosion and recession. The chapter thus presents information which should assist city officials and other affected parties in understanding the potential risk of shoreline erosion in the study area, and describes the measures available for reducing that risk, along with associated costs.

Analytic procedures and criteria were presented to explain the characteristics, advantages, and disadvantages of structural shore protection measures, to show how the erosion risk areas and recommended setback distances for new urban development are calculated, and to describe the relationship between land use management practices and shoreline erosion. These procedures and criteria should be helpful in the detailed design of proposed developments and shore protection measures.

Alternative structural shore protection measure designs and cost estimates were presented. A combination of bluff toe protection, bluff slope stabilization, and surface water and groundwater drainage control will be required to adequately prevent bluff recession. Bluff toe protection measures evaluated included a rip-rap revetment, three different types of bulkheads, groins, and reconstruction of the Milwaukee South Shore breakwater. The capital costs of these structures were estimated to range from $125 to $1,400 per linear foot of shoreline. However, the lowest cost alternative, the groin system, may provide adequate protection only for that portion of the study area already protected by the Milwaukee South Shore breakwater. Bluff slope stabilization could be accomplished by cutting back, regrading, and revegetating the slope, at a cost ranging from $107 to $152 per linear foot of shoreline, or by terracing the bluff slope with retaining walls, at a cost of about $2,400 per linear foot of shoreline. Surface water drainage control could be provided at a cost of approximately $10 per linear foot of shoreline. Although detailed geotechnical analyses are required to design a groundwater drainage system, preliminary investigations indicate that only about 600 feet of the shoreline may require groundwater drainage to provide stable bluff slopes. This groundwater drainage could be provided by a vertical well system at a cost of about $30 per linear foot of shoreline. Annual maintenance costs were also estimated in the chapter.

Erosion risk distances and setback distances for new urban development from the existing bluff edge were identified for each of the 19 bluff recession reaches within the actively eroding shoreline of the study area. The erosion risk distances and setback distances were developed under assumed nonstructural and structural shore protection measures. The erosion risk distance is the distance from the existing bluff edge which would be affected by recession of the bluff over time, and by regrading of the bluff slope as required to achieve a stable slope of about one on two and one-half. The setback distance is comprised of the erosion risk distance plus a minimum facility setback distance, which would range from 100 to 200 feet.

Nonstructural erosion risk distances and setback distances are shown in Appendix C for a 50-year period. About 20 acres of land is contained within the 50-year nonstructural erosion risk distance, or about 12 percent of the study area. This land has a current economic value of about $650,000.

Structural erosion risk distances and setback distances are shown in Appendix D. These distances are shown with bluff toe protection with a bulkhead, and with bluff toe protection with a structure other than a bulkhead. A lesser distance may be required to achieve a stable bluff slope with use of a bulkhead, since the slope would have to be regraded only from the top of the bulkhead. The structural erosion risk distance from the existing bluff edge if a bulkhead were used to provide bluff toe protection would include about five acres of land, or about 3 percent of the study area. This land has a current economic value of about $160,000. If a structure other than a bulkhead were used to provide bluff toe protection, the structural erosion risk distance would include about seven acres of land, or about 4 percent of the study area, having a current economic value of about $230,000.

Land use management measures related to shore erosion and protection were described in the chapter. The City of St. Francis zoning ordinance could be amended to include provisions directly related to shoreline erosion hazards. Educational and informational efforts could also be undertaken by the City to inform affected parties of this erosion risk and potential control measures. Land use management activities of particular concern to shoreline erosion are construction site erosion and stormwater drainage. Provisions were presented which would aid in the control of these activities.

Chapter IV

RECOMMENDATIONS AND CONCLUSIONS

INTRODUCTION

This chapter provides recommendations for structural shore protection measures, shoreline erosion risk and setback distances, and proper land use management of the shoreline area of the City of St. Francis. The purpose of these recommendations is to provide some assistance and guidance to the public officials and to potential land developers and other affected parties as decisions are made concerning the development of the shoreline area and the control of shoreline erosion and bluff recession. The inventory data and evaluation analyses presented in this report provide the basis for the recommendations.

Foremost, the recommendations presented herein are intended to be technically effective--proposing sound measures for reliable protection against property damage and risk to human safety caused by shoreline erosion and bluff recession. The recommendations are also intended to be feasible, with implementation procedures selected in consideration of the City's and the public's interest in Lake Michigan shoreline protection, of programs available to help implement the recommended control measures, and of the need to allow reasonable use of the land within the study area. Finally, the recommendations reflect the concerns and preferences of the local community, which were incorporated into the study results through the guidance provided by the study Advisory Committee created by the City.

STRUCTURAL SHORE PROTECTION MEASURES

The determination of whether structural shore protection measures are required is dependent primarily upon whether urban development occurs within the study area. In the absence of adequate shore protection, such development would present a high risk of severe damage from continued bluff recession. If development does not occur within the study area, certain structural shore protection measures may not be economically justified. The determination of the potential for development of the study area should be based, in part, upon the shoreline erosion considerations set forth in this report.

With Minimum Urban Development Outside the Power Plant Site

The dike and revetments protecting the shoreline of the Wisconsin Electric Power Company Lakeside power plant site appear to be functional, and the bluff slope behind these structures is stable. Accordingly, under the minimum development alternative, these shoreline protection measures would be retained, and various forms of urban development could be permitted to occur within the power plant site west of the structural setback distances, as well as outside the power plant site west of the nonstructural setback distances set forth in Appendix C, without the need for additional major structural shore protection measures. The existing structures at the power plant site would have to be properly maintained. If the bluff slope at the power plant site is disturbed, care would have to be taken to ensure that the slope is regraded to a stable slope and that adequate vegetative cover is provided.

Map 11

RECOMMENDED STRUCTURAL SHORE PROTECTION MEASURES IF MINIMUM URBAN DEVELOPMENT OCCURS OUTSIDE THE EXISTING WEPCO LAKESIDE POWER PLANT SITE

Source: SEWRPC.

If minimum urban development is envisioned in the study area beyond the power plant site, the construction of additional major structural shore protection measures may not be justified. The longer the provision of such measures is delayed, however, the less amount of land will remain for development. As shown in Appendix C, without the provision of additional structural shore protection measures, the 50-year erosion risk distance would lie close to, although still east of, S. Lake Drive. Thus, no major facilities would likely be damaged by bluff recession within this 50-year period. At any time during these 50 years, shore protection structures could be provided to protect S. Lake Drive, since an adequate stable slope distance is included within the erosion risk distance.

Map 11 shows the structural shore protection measures recommended under the minimum development alternative. The maintenance of existing structural shore protection measures along the 3,500 feet of shoreline of the power plant site, with no additional structural shore protection measures being provided, would allow the potential development of about 40 acres of land, or 25 percent of the study area. This 40-acre area includes the main power plant building, which covers three acres. Development on seven of those 40 acres should be limited to public utility and recreational facility use, based upon the minimum facility setback distances set forth in Chapter III. If the City were to utilize a different minimum facility setback distance, or if certain shore protection measures were selected to reduce the stable slope distance, additional areas could be developed. Maintaining the existing protection structures along the 3,500 feet of power plant site shoreline would cost a minimum of $25,000 per year. The remaining 6,120 feet of study-area shoreline would receive no major structural protection under this alternative, although such protection could be provided in the future to protect S. Lake Drive. In addition, relatively low-cost shore protection structures could be provided to slow the rate of bluff recession. The undeveloped land, with an areal extent of about 100 acres, or 62 percent of the study area, would be used as open space, parkland, or other uses which do not require the construction of major facilities and buildings. About 21 acres, or 13 percent of the study area, located west of S. Lake Drive are expected to be retained for use as a substation by the Wisconsin Electric Power Company.

With Maximum Development Outside the Power Plant Site

Under the maximum development alternative, the dike and revetments protecting the shoreline of the Lakeside power plant site would be retained, as under the minimum development alternative. Additional structural shore protection measures would be provided for the remaining actively eroding shoreline area. These structures would allow for additional urban development along S. Lake Drive.

Map 12 shows the recommended structural shore protection measures which would allow maximum development to occur within the study area. No development would be permitted to occur within the structural setback distances. Maintenance of the existing structural shore protection measures would be required along 3,500 feet of shoreline, and new shore protection measures would be constructed along 4,440 feet of shoreline. The northernmost 1,680 feet of study-area shoreline would require no protection because the bluff slopes are stable at the present time. Structural shore protection measures would be constructed along Bluff Analysis Section 6 to protect Bay View Park, to provide continuity of shore protection, and to prevent flanking of the revetment located north of the power plant. The map shows the erosion risk and setback distances with bluff toe protection provided by a bulkhead. As discussed in Chapter III, if a structure other than a bulkhead were used to provide bluff toe protection, the erosion risk and setback distances would be greater. The structural shore protection measures as shown on the map would allow the development of about 52 acres of land, or 32 percent of the study area.

The following structural shore protection measures are recommended if maximum development within the study area is desired:

1. Bluff toe protection should be provided along the entire actively eroding shoreline. This toe protection could be provided by either revetments or bulkheads. In Bluff Analysis Section 6, it is recommended that a relatively low-cost structure, such as a groin system with artificial beach fill, be considered. This reach of shoreline is partially protected by the Milwaukee South Shore breakwater. All bluff toe protection structures should be designed for a 50-year life. If the lowest cost alternative--a concrete cantilevered bulkhead in Bluff Analysis Sections 1 through 5 and a groin system with artificial beach fill in Section 6--is selected, a capital cost of about $1.3 million, or an average of $300 per linear foot of shoreline, would be required. Annual maintenance costs would be expected to approximate $20,000.

Map 12

RECOMMENDED STRUCTURAL SHORE PROTECTION MEASURES TO ALLOW MAXIMUM URBAN DEVELOPMENT WITHIN THE STUDY AREA

Source: SEWRPC.

2. Bluff slope stabilization should be provided at all sites which receive bluff toe protection. All slopes should be regraded to a maximum slope of one on two and one-half. Either a cutback or terracing method may be used. The lowest cost alternative, the cutback method, would require a capital cost of about $430,000, or $107 per linear foot of shoreline. Annual maintenance costs would be expected to approximate $5,000.

3. Stormwater management facilities should be provided to prevent ponding and flooding within the study area, and to prevent excessive stormwater runoff from flowing over the top of the bluff along the entire shoreline. To the extent practicable, piped storm sewer facilities should be used with properly designed outfalls at lake level. As an alternative, carefully designed open diversion channels may be utilized to intercept stormwater flow and discharge it safely to the toe of the bluff. Such open diversion channels would require a capital cost of about $40,000, or $10 per linear foot of shoreline, and an annual maintenance cost of about $2,000.

4. A detailed geotechnical study should be conducted to define the water-bearing subsurface strata and the groundwater flow in the study area, as well as to help in the design of a groundwater drainage system to prevent excessive groundwater seepage from the bluff face. Preliminary investigations indicate that a groundwater drainage system should be provided in Bluff Analysis Sections 3 and 4. A vertical well system could be used to drain the groundwater to the base of the bluff. A vertical well system would require a capital cost of about $20,000, or $30 per linear foot of shoreline, and an annual operation and maintenance cost of about $1,000.

5. All structural shore protection measures--bluff toe protection, slope stabilization, stormwater management, and groundwater drainage control--should be designed and constructed in a coordinated, comprehensive manner. All shore protection structures should be constructed either prior to, or concurrently with, any new urban development in the study area.

6. All structural shore protection measures should be carefully maintained throughout their useful life to ensure a continued adequate level of protection.

7. All structural shore protection measures should be designed in conformance with the design criteria set forth in Table 11 in Chapter III.

The recommended structural measures and associated setback distance may be modified in the planning for development of the study area, as well as in the detailed engineering design of the structures. The structures implemented must be compatible with the development, as well as provide the desired level of shore protection. Thus, the recommendations set forth above are intended to be used as a guide in the final selection of shore protection structures.

LAND USE MANAGEMENT

Erosion Risk Distances and Setback Distances

To assure the uniform application of, and adequate compliance with, necessary restrictions within the erosion risk distances and setback distances, it is recommended that the City of St. Francis zoning ordinance be amended to include provisions which, in the public interest, would regulate land uses and facility locations within these specified distances from the bluff edge. The amendments would include provisions defining pertinent terms, designating the lands to be regulated, specifying the necessary regulation of land use and facility location, specifying the regulation of certain land disturbance activities, and describing procedures for modifying the location and extent of the designated setback distances. Erosion risk and setback distances are shown on large-scale topographic maps in Appendices C and D of this report. Appendix B sets forth recommended amendments to the City of St. Francis zoning ordinance which would regulate, in the public interest, land uses in relation to shoreline erosion and bluff recession risks and shore protection measures.

The setback distance for buildings and other facilities from the edge of the bluff along shoreline areas currently--or which would be--protected by properly designed, constructed, and maintained structural shore protection measures should be determined using the following formula--graphically illustrated in Figure 30 of Chapter III of this report:

Structural Setback Distance = Structural Erosion Risk Distance + Minimum Facility Setback Distance

Where: Structural Erosion Risk Distance = Net Stable Slope Distance = Distance Required to Achieve a One on Two and One-Half Bluff Slope

The minimum facility setback distance is intended to provide a safety factor to prevent damages which could be caused by major storms or shore protection structure failure, and to provide an open space area which can be effectively utilized for surface water and groundwater drainage and control. The minimum facility setback distance prevents facilities from being placed too close to the bluff edge, which could reduce slope stability. A minimum facility setback distance also maintains the aesthetic amenities of the bluff edge, provides human safety factors, and ensures that public utilities are located an adequate distance from the bluff edge. Based on the above considerations, it is recommended that a minimum facility setback distance of 100 feet be applied for all new permanent buildings and facilities for shoreland areas protected by structural shore protection measures. Structural setback distances would also apply to those portions of the Lake Michigan shoreline which are currently stabilized, even if no shore protection structure is in place.

A structural shore protection measure may be considered effective and properly designed if it meets the criteria set forth in Table 11 of Chapter III of this report. The zoning ordinance amendments should require that proposed development along the Lake Michigan shoreline be protected by structural shore protection measures meeting the criteria set forth in Table 11.

The nonstructural setback distance should be used for all actively eroding portions of the shoreline which would not be protected by proper structural shore protection measures; and it should consist of the nonstructural erosion risk distance--defined as the expected 50-year bluff recession distance from the existing bluff edge, plus a net stable slope distance, plus a minimum facility setback distance. The required nonstructural distance should be calculated using the following formula--graphically illustrated in Figure 29 of Chapter III of this report:

Nonstructural Setback Distance = Nonstructural Erosion Risk Distance + Minimum Facility Setback Distance

Where: Nonstructural Erosion Risk Distance = 50-Year Bluff Recession Distance + Net Stable Slope Distance

For shoreland areas not protected by structural shore protection measures and which are actively eroding, it is recommended that an additional safety factor be incorporated into the minimum facility setback distance because future bluff recession rates could differ substantially from historic bluff recession rates.

For the nonstructural setback distance, the following minimum facility setback distances are recommended:

- 200 feet for all permanent buildings and facilities except public utilities and outdoor recreational facilities.

- 100 feet for public utilities and outdoor recreational facilities.

Prohibited, Conditional, and Permitted Uses: Within the calculated structural and nonstructural setback distances, the recommended City of St. Francis zoning ordinance amendments prohibit the location, relocation, development, or redevelopment of major buildings and facilities, including streets. Variances could be granted for relocatable buildings on a case-by-case basis, based upon careful consideration of the impact on the property owner, the erosion risk involved, and alternatives for development.

The recommended zoning ordinance amendments specify as conditional uses within the calculated structural and nonstructural setback distances: land disturbance activities, tree cutting or vegetation removal, and the construction of structural shore protection measures. Such conditional uses would require, for approval, that specified criteria or provisions be met.

Permitted uses within the structural and nonstructural setback distances, unless restricted by other zoning ordinance provisions, include: open space uses, storage of portable equipment and supplies, accessory buildings such as storage sheds, and minor facilities such as driveways, sidewalks, patios, and fences. Permitted uses thus include uses and the placement of materials which would not increase stresses on the bluff, which could reduce slope stability.

Modification of the Structural and Nonstructural Setback Distances: It is recommended that provision be made for the modification of the calculated structural and nonstructural setback distances set forth in the recommended zoning ordinance amendments, upon submittal to the City by an applicant or property owner of an acceptable engineering study and report which clearly indicates that the stable slope conditions are, in fact, different from those indicated herein. The evaluation of the stability of the slope and the identification of the specific stable slope angle will, in most cases, require a field survey and technical assistance from a qualified professional geotechnical engineer. The requirement for structural protection measures would be allowed to be waived if the applicant or property owner presents acceptable evidence that the proposed facility and adjacent property can be adequately protected without the recommended structural shore protection measures. Minimum facility setback distances may be modified by the City in the consideration of specific plans for development.

Periodic Updating of Nonstructural Erosion Risk Distances and Setback Distances: It is recommended that, if urban development of the study area does not occur, nonstructural erosion risk distances be reviewed and revised as necessary to reflect changes in the bluff characteristics and to incorporate new bluff recession rates into the long-term average rate. The formulas for establishing setback distances set forth in this report should continue to be used with the new recession rates and bluff characteristics. Bluff heights should be redefined at approximately 10-year intervals, and the large-scale topographic maps of the shoreland area prepared under this study should be updated. Similarly, bluff recession rates should be remeasured at approximately 10-year intervals, as appropriate aerial photography and updated topographic maps become available. The 1963 aerial photographs by the Regional Planning Commission should continue to be used for measuring recession. A stable slope of one on two and one-half should continue to be used, except where site-specific studies indicate a stable slope that is not one on two and one-half. Appendix C should be updated at approximately 10-year intervals to reflect the revisions in bluff characteristics and recession rates.

Construction Site Erosion Control

It is recommended that the City of St. Francis incorporate provisions for construction site erosion control into its subdivision control ordinance. While these provisions could be applied throughout the municipality, for the purposes of this study they apply only to developments proposed east of S. Lake Drive. The following construction site erosion control provisions are recommended:

1. One inch equals 100 feet scale topographic maps prepared by the Southeastern Wisconsin Regional Planning Commission should be included with the subdivision preliminary plat submittals. The maps should show the existing ground surface; areas with steep slopes; street grades and profiles; proposed gutters, storm sewers, open drainage channels, water diversions, drainage easements, and soil erosion control practices; and the type and location of shoreline erosion control measures.

2. Plans for development should indicate the suitability of soils for development and identify areas covered by highly erodible soils.

3. Provisions should be made to accommodate stormwater runoff since construction activities change soil and surface conditions. Such changed conditions may aggravate shoreline erosion problems.

In addition, the City should encourage land developers within the study area to utilize proper construction practices and good soil conservation measures. During construction, the smallest practicable area of soil should be exposed at any given time for as short a duration of time as possible. Temporary vegetation, mulching, or other cover should be encouraged to protect critical areas, and permanent vegetation should be installed as soon as practicable. Tracking or dropping of dirt or other materials from the site onto any public or private street should be minimized.

Stormwater Management

Amendments to the City of St. Francis subdivision control ordinance are also recommended to assure that development within the Lake Michigan shoreland area is served by a stormwater drainage system that is economical and effective, and which has the capacity to safely accommodate stormwater runoff from the planned development without exacerbating shoreline erosion or bluff recession problems. The following stormwater management provisions are recommended:

1. Minor stormwater system components should be designed to accommodate flows expected from a 10-year recurrence interval storm event under

planned development conditions.[1] Major stormwater system components should be designed to accommodate flows expected from a 100-year recurrence interval storm event under planned development conditions.[2]

2. Surface stormwater runoff should be prevented from being discharged uncontrolled over the top of the bluff, and prevented from damaging bluff toe protection measures.

3. The stormwater drainage systems should be carefully adjusted to the topography of the land in order to minimize grading and drainage problems, except where modifications are needed to prevent surface stormwater runoff from being discharged over the top of the bluff.

4. Stormwater storage measures such as detention ponds and parking lot or roof top storage devices should not be utilized unless detailed engineering and geotechnical analyses indicate that such measures would not threaten the stability of the bluff slope.

In addition to these provisions, the public works program of the City of St. Francis should provide for the continued maintenance of stormwater management facilities--including periodic inspection of facilities; timely repair of facilities; cleaning of storm sewers and open channels; maintenance of channel lining materials; and periodic removal of accumulated sediments. Such a maintenance program will help prevent hazards which may result if such facilities become defective--including potentially catastrophic bluff slope failure.

SUMMARY

This chapter has set forth recommendations for structural erosion control measures and related land use management measures for the Lake Michigan shoreline of the City of St. Francis. The information provided in this chapter is intended to inform public officials and potential land developers of the erosion risks associated with shoreland development and of the means available to reduce the risk of damages from such erosion.

The study results indicate that urban development could be accommodated within up to a 40-acre land parcel without additional shore protection being required. If no development is to occur within the study area beyond this 40-acre land parcel, and if the City agrees to tolerate further loss of land to bluff reces-

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[1]The minor stormwater drainage system is intended to minimize the inconveniences attendant to inundation from more frequent storms. The minor drainage system consists of sideyard and backyard drainage swales, street curbs and gutters, roadway ditches, storm sewers, and some storage facilities. It is composed of the engineered paths provided for the stormwater runoff to reach the receiving streams and watercourses during these more frequent storm events.

[2]The major stormwater drainage system is designed for conveyance of stormwater runoff during major storm events when the capacity of the minor system is exceeded. The major stormwater drainage system consists of the entire street cross-section and interconnected drainage swales, watercourses, and stormwater storage facilities.

sion and shoreline erosion, no additional major expenditures may be expected to be required for shore protection for the foreseeable future, other than for maintenance of the existing structural shore protection measures.

If additional urban development is desired in the study area, however, then structural shore protection measures should be provided. Carefully designed bluff toe protection, bluff slope stabilization, stormwater management, and groundwater drainage control measures are recommended. These structural measures would be expected to require a minimum capital investment of about $1.8 million, or about $400 per linear foot of actively eroding shoreline, and an annual maintenance cost of about $30,000. Provision of these measures would allow the development of up to 52 acres of land, including the above-mentioned 40-acre land parcel.

The erosion risk distances and the setback distances from the existing Lake Michigan bluff edge can be used as a basis for public informational and regulatory measures designed to guide urban development in proper relation to the bluff recession and shoreline erosion risk. This chapter includes recommended amendments to the City of St. Francis zoning ordinance which relate development to the risk of erosion, and thereby protect the public safety and welfare.

On the basis of the nonstructural erosion risk distances presented in Chapter III, setback distances are specified to protect those areas potentially subject to erosion within a 50-year time period. For shoreland areas actively eroding and not protected by structural shore protection measures, a minimum facility setback distance of 100 feet for public utilities and outdoor recreational facilities is recommended, and a setback of 200 feet is recommended for other major permanent buildings and facilities. Structural erosion risk distances and setback distances are provided for those areas which are or will be protected by structural shore protection measures. For shoreland areas which are currently stabilized, or which will be protected by structural shore protection measures, a minimum facility setback distance of 100 feet is recommended for all major permanent buildings and facilities. All of these setback distances are intended to be incorporated as amendments into the city zoning ordinance.

Uses recommended to be prohibited within the specified nonstructural and structural setback distances include the location, relocation, development, or redevelopment of major buildings and facilities, including streets. Recommended conditional uses include land disturbance activities, tree cutting, and the construction of structural shore protection measures. Uses recommended to be permitted within the setback distances include open space uses, the storage of portable equipment and supplies, accessory buildings such as storage sheds, and minor facilities such as driveways, sidewalks, patios, and fences.

It is recommended that the city zoning ordinance contain provisions which would allow property owners or applicants the opportunity to present information which could be used to modify the required setback distance. In addition, it is recommended that the nonstructural erosion risk and setback distances be refined and updated at approximately 10-year intervals.

Construction site erosion control and stormwater management provisions which pertain to development within the study area are recommended to be added as amendments to the City's subdivision control ordinance. While these provisions could be applied throughout the municipality, for the purposes of this study they apply only to development occurring east of S. Lake Drive.

Chapter V

SUMMARY

INTRODUCTION

The erosion and recession of the coastal bluffs along the Lake Michigan shoreline in the City of St. Francis constitutes a serious loss of valuable land, contributes to the pollution of the near-shore waters of Lake Michigan, and creates a high risk of severe damage to any new urban development in the coastal zone. Bluff recession rates in the City of St. Francis range up to over five feet per year, averaging almost three feet per year along the actively eroding bluff sections of the shoreline. This bluff recession results in the loss of approximately 0.3 acre of land surface and 535,000 cubic feet of shore material each year.

The shore erosion and bluff recession along the Lake Michigan shoreline of the City of St. Francis may be managed by a coordinated set of structural and nonstructural measures which reduce shoreline erosion and the damages that result from such erosion. Structural shore protection measures which may be applicable to the study area include revetments, bulkheads, groins, off-shore breakwaters, and surface and groundwater drainage controls. Nonstructural measures include land use regulations, building setback requirements, and land use management measures related to shore erosion and protection.

PURPOSE AND SCOPE

The primary purpose of this coastal erosion and related land use management study was to identify high erosion risk areas along the Lake Michigan shoreline, and to recommend measures for shore erosion and bluff recession control, and suitable related land use regulations for the coastal zone. The study quantified the extent of shoreline erosion and bluff recession which may be expected to occur over time along the Lake Michigan shoreline of the City of St. Francis in the absence of any structural control measures; evaluated alternative structural shore protection measures; identified shoreline erosion risk distances and associated setback distances for buildings and facilities along shoreline reaches if proper shore protection structures are provided, as well as if such structures are not provided; and recommended a set of regulations which may be incorporated into the existing city zoning and subdivision ordinances to protect proposed new urban development within those shoreland areas susceptible to erosion and bluff recession. The study was carried out under the guidance of a coastal erosion Advisory Committee created by the City and composed of representatives of the Wisconsin Electric Power Company, the City of St. Francis, and interested and concerned citizens. The study itself was subsequently carried out cooperatively by the staffs of the City and the Regional Planning Commission.

INVENTORY FINDINGS

The coastal erosion and related land use management study area was defined under the study as the existing 130-acre "Lakeside" property owned by the Wisconsin Electric Power Company and the remaining 31-acre Lake Michigan shoreline area within the City of St. Francis lying essentially easterly of S. Lake Drive. The study area is comprised of those lands which most directly affect, or are most directly affected by, the Lake Michigan erosion process. The study area encompasses approximately 161 acres of land, and 9,620 feet of Lake Michigan shoreline.

Elements of the natural resource base of the study area pertinent to the understanding of coastal erosion processes include bedrock geology and glacial deposits, soils, bluff and beach characteristics, groundwater resources, and climate. The study area is underlain by Silurian, Ordovician, Cambrian, and Precambrian bedrock. Up to 100 feet of unconsolidated glacial deposits cover the bedrock, and include layers of the Oak Creek Formation, the New Berlin Formation, and the Zenda Formation. About 60 percent of the study area is covered by Ozaukee soils which have a low infiltration capacity, low permeability, and poor drainage. The remaining 40 percent of the study area is covered by disturbed soils.

Although some bluff heights within the City of St. Francis reach nearly 70 feet, most of the shoreline has bluffs ranging from 40 to 50 feet in height. The bluffs are comprised of glacial till, silt, clay, sand, and gravel. At the time of the field surveys conducted under the study, most of the shoreline had a beach width of less than 20 feet, although in places the beach width exceeded 60 feet.

Along the City of St. Francis shoreline, groundwater generally flows toward Lake Michigan. Two major aquifers underlie the coastal area: the deep sandstone aquifer and the Niagara dolomite aquifer. Numerous groundwater discharges and seepages occur on the bluff slopes, contributing to the instability of these slopes.

In 1980, about 43 percent of the study area consisted of unused, open lands. Communication and utility land uses accounted for an additional 31 percent of the study area. The remaining 26 percent of the study area was used for parks, streets, parking lots, and surface water. The entire study area is currently placed in zoning districts which permit urban development. The city zoning ordinance does not include any provisions for the regulation of development and redevelopment in relation to Lake Michigan shoreline erosion hazards. Such provisions have not been required in the past because the entire shoreline is owned by the Wisconsin Electric Power Company and by Milwaukee County.

The Wisconsin Electric Power Company presently owns over 70 percent of the study area, 42 percent of which is vacant land. The 21-acre parcel of land in the study area lying west of S. Lake Drive is expected to continue to be used as a substation by the power company.

The most important Lake Michigan coastal problem in the City of St. Francis is recession of the bluffs. In December 1983, a detailed survey was conducted to evaluate erosion-related characteristics of the bluffs. The results of the inventory indicated that the primary cause of bluff recession in the study area is bluff toe erosion by wave action. Groundwater seepage also is a major cause of slope failure in some portions of the study area. Shallow sliding is the most common type of slope failure on the St. Francis bluffs. On-shore protection structures presently provide protection for approximately 36 percent of the shoreline. From 1963 through 1980, the bluff recession rate along the unprotected reaches of shoreline, as determined by the Regional Planning Commission, averaged 2.7 feet per year. About 24 percent of the unprotected reaches of shoreline had a bluff recession rate of less than 1.0 foot per year. The highest recession rate measured by the Regional Planning Commission for the period 1963 through 1980 was 5.6 feet per year at the extreme southern end of the study area.

EVALUATION OF COASTAL PROBLEMS AND CONTROL MEASURES

The identification of the shoreland areas which are expected to be affected by shoreline erosion and bluff recession enables public officials and other concerned and affected parties to better assess potential erosion losses and to evaluate alternative shoreline erosion control and related land use management measures. Specific structural shore protection measures required at any particular site can be determined only on the basis of a detailed engineering analysis of the physical characteristics of the study area, the causes of erosion, the degree of erosion expected, property values, and the intended development. Bluff toe protection measures evaluated for the City of St. Francis included a rip-rap revetment, three different types of bulkheads, groins, and reconstruction of the Milwaukee South Shore breakwater. The installation of the bluff toe protection structures would entail a capital investment of from $125 to $1,400 per linear foot of shoreline. The groin system, which is the lowest cost alternative, may provide adequate protection for only that portion of the study area which is already partially protected by the Milwaukee South Shore breakwater. Surface water drainage control could be provided at a cost of approximately $10 per linear foot of shoreline. Groundwater drainage, which may be necessary only for 6 percent of the shoreline, could be provided at a cost of about $30 per linear foot of shoreline. Bluff slope stabilization could be accomplished by cutting back, regrading, and revegetating the slope, at a cost of from $107 to $152 per linear foot of shoreline; or by terracing the bluff slope with retaining walls, at a cost of about $2,400 per linear foot of shoreline. Annual maintenance costs for shore protection structures generally range up to 2 percent of the capital cost.

Erosion risk and setback distances from the existing bluff edge were identified for each of 19 bluff recession reaches under the following alternatives: 1) 50-year nonstructural, 2) structural having bluff toe protection with a bulkhead, and 3) structural having bluff toe protection with a structure other than a bulkhead. The erosion risk distance is defined as the distance from the existing bluff edge which may be expected to be affected by recession of the bluff over a 50-year time period, and by the regrading of the bluff slope to achieve a stable slope of about one on two and one-half. The setback distance is defined as the erosion risk distance plus a minimum facility setback distance ranging from 100 to 200 feet. The area contained within the 50-year nonstructural erosion risk distance from the existing bluff edge includes about 20 acres of land, or about 12 percent of the study area, and has a current economic value of about $650,000. The area contained within the structural erosion risk distance from the existing bluff edge--if a bulkhead should be used to provide bluff toe protection--includes about five acres of land, or about 3 percent of the study area. This land has a current economic value of about $160,000. If a structure other than a bulkhead is used to provide bluff toe protection, the structural erosion risk distance would include about seven acres of land, or about 4 percent of the study area, having a current economic value of about $230,000.

Land use management measures related to shore erosion are necessary to protect new urban development within the study area from damage or destruction. The City of St. Francis zoning ordinance could be amended to include provisions directly related to shoreline erosion hazards. Educational and informational efforts could also be undertaken by the City to inform affected parties of this erosion risk and of potential control measures. Land use management activities of particular concern to shoreline erosion are construction site erosion control and stormwater management.

RECOMMENDATIONS

The findings and recommendations of this study are intended to help inform city officials and potential land developers of the location and extent of the Lake Michigan shoreline area subject to a risk of erosion, and of actions that can help to reduce that risk. The determination of whether structural shore protection measures are required is primarily dependent upon whether urban development will be permitted to occur within the study area. The study results indicated that urban development could be permitted within an approximately 40-acre land parcel without additional shore protection being required. If no development is permitted to occur within the study area beyond this 40-acre land parcel in the future, no additional expenditures should be necessary for shore protection for at least the next 50 years, other than for maintenance of the existing structural shore protection measures. Maintenance of the existing structures entails a minimum annual cost of about $25,000.

If additional urban development is desired in the study area, however, then structural shore protection measures should be provided. Bluff toe protection, bluff slope stabilization, stormwater management, and groundwater drainage control are recommended. Depending upon the type of structure selected, bluff toe protection would entail a capital cost of from $1.2 million to $5.1 million, and an annual maintenance cost ranging from $15,000 to $50,000. Bluff slope stabilization could entail a minimum capital cost of about $430,000 and an annual maintenance cost of about $5,000, if all of the remaining unprotected shoreline of the study area were to be protected. Stormwater management measures may be expected to cost up to $40,000 and require an annual maintenance cost of about $2,000. Groundwater drainage could be provided at a cost of about $20,000, with an annual maintenance cost of about $1,000. A reasonable estimate of the total capital cost of bluff toe protection utilizing a concrete cantilevered bulkhead, bluff slope stabilization, and storm- and groundwater protection measures is $1.8 million, or about $400 per linear foot of shoreline, with an annual maintenance cost of $30,000. The provision of shore protection measures to areas not now protected would allow the development of an additional 12 acres of land, at a capital cost of about $150,000 per acre and an annual maintenance cost of $2,500 per acre. The provision of the shore protection measures would also allow an additional seven acres to be fully developed for urban use, rather than only for public utility and public recreational use.

Recommended amendments to the City of St. Francis zoning ordinance which would, in the public interest, regulate shore protection, land uses, activities, and facility locations within the specified setback distances are set forth in Appendix B of this report.

On the basis of the nonstructural erosion risk distances presented in Chapter III, setback distances are specified to protect those areas potentially subject to erosion within a 50-year time period. For shoreland areas actively eroding and not protected by structural shore protection measures, a minimum facility setback distance of 100 feet for public utilities and outdoor recreational facilities is recommended, and a setback of 200 feet is recommended for other major permanent buildings and facilities. Structural erosion risk distances and setback distances are provided for those areas which are or will be protected by structural shore protection measures. For shoreland areas which are currently stabilized, or which will be protected by structural shore protection measures, a minimum facility setback distance of 100 feet is recommended for all major permanent buildings and facilities. All of these setback distances are intended to be incorporated as amendments into the city zoning ordinance.

Uses recommended to be prohibited within the specified nonstructural and structural setback distances include the development or redevelopment of major facilities and buildings, including streets. Conditional uses include land disturbance activities, tree cutting, and the construction of structural shore protection measures. Uses recommended to be permitted within the setback distances include open space uses, the storage of portable equipment and supplies, accessory buildings such as storage sheds, and minor facilities such as driveways, sidewalks, patios, and fences.

It is recommended that the city zoning ordinance contain provisions which would allow property owners or applicants the opportunity to present information which could be used to modify the required setback distance. In addition, it is recommended that the nonstructural erosion risk and setback distances be refined and updated at approximately 10-year intervals.

Construction site erosion control and stormwater management provisions which pertain to development within the study area are recommended to be added as amendments to the city subdivision control ordinance.

The adoption and implementation of the management measures herein recommended for the Lake Michigan shoreland area of the City of St. Francis will help reduce the serious bluff recession problems affecting the city shoreline. The implementation of these recommended measures may thus be expected to provide a safer, more healthful, and more pleasant, as well as more orderly and efficient, environment within the shoreland areas, promoting the public health, safety, and general welfare.

Appendix A

GLOSSARY OF SHORELINE EROSION-RELATED TERMS

BEACH: An area of unconsolidated material which extends landward from the ordinary low-water line to the line marking a distinct change in physiographic form or the beginning of permanent terrestrial vegetation.

BLUFF: A high, steep bank or cliff located to the landward side of a beach.

BLUFF RECESSION RATE: The rate at which the bluff recedes because of erosion by the adjacent water body and because of unstable slope conditions.

BOULDERS: Rock particles with a diameter of more than 10 inches.

BREAKWATER: An off-shore barrier which breaks the force of waves and provides shelter from wave action.

BULKHEAD: A structure of wood, stone, concrete, or steel erected along and parallel to a portion of a shoreline primarily to prevent erosion and other damage by wave action. Also called a seawall.

CLAY: Very fine-grained soil with a particle diameter of less than 0.00015 inch.

COBBLES: Rock particles with a diameter ranging from 3 to 10 inches.

DEEP WATER: Area where surface waves are not influenced by the lake bottom. In general, deep water is considered water deeper than one-half the surface wavelength.

EROSION: The wearing away of land by water and wind action.

FILTER CLOTH: Synthetic fabric with openings of a size which allows water to pass through and escape but which prevents soil from passing through and being washed away.

FLANKING: A cause of failure of shore protection structures where the sides of the structure are eroded by wave action.

GLACIAL TILL: Unstratified glacial debris, consisting of unsorted particles ranging from clay to boulders.

GRAVEL: Rock particles with a diameter ranging from 0.18 inch to 3 inches.

GROIN: A structure projecting outward from the shore designed to protect the shore from erosion and to arrest sand movement along the shore, thereby encouraging the formation of increased beach widths.

GROSS STABLE SLOPE DISTANCE: The total horizontal distance of a bluff with a stable slope. In the City of St. Francis, a stable bluff slope along the Lake Michigan shoreline may be assumed to have an angle with a horizontal of approximately 22°. This bluff slope would result in a gross stable slope distance that is about two and one-half times the bluff height.

GROUNDWATER SEEPAGE: The movement of water--through cracks, pores, and interstices--out of a material body. Groundwater seepage from bluff faces may decrease the grain-to-grain contact pressure in the soil, reduce the frictional resistance of the soil to stress, and add weight to the bluff.

LONGSHORE CURRENTS: Water currents running generally parallel to the shoreline and usually caused by waves breaking at an angle to the shoreline. Longshore currents transport sediment parallel to the shore.

NET STABLE SLOPE DISTANCE: The gross stable slope distance minus the existing horizontal distance of the bluff slope. It represents the distance that the top of the bluff would need to recede, or be regraded, to form a stable bluff slope which would not likely be affected by major types of slope failure such as slumping or sliding.

NONSTRUCTURAL EROSION RISK DISTANCE: The distance from the existing bluff edge that is expected to be affected by continued bluff recession, and by regrading of the bluff face to a stable slope (the net stable slope distance). This distance applies to those shoreline areas which are actively eroding and not protected, or planned to be protected, by shore protection structures.

NONSTRUCTURAL SETBACK OVERLAY DISTRICT DISTANCE: For Lake Michigan shoreland areas not protected by properly designed, constructed, and maintained shore protection structures, the distance from the existing bluff edge which is expected to be affected by shoreline erosion and bluff recession over a 50-year period, or by regrading of the bluff slope as needed to achieve a stable slope. The nonstructural setback distance also includes a minimum facility setback distance.

OVERTOPPING: A condition where the water level, or wave heights, exceed the top of a shore protection structure. Overtopping can remove small particles from the foundation of a structure, thereby weakening that foundation.

PHREATIC ZONE: The area below the upper boundary of the water table in soils, in which water moves under the influence of gravity and which may contribute water to springs and seeps.

REVETMENT: A facing of stone, concrete, or other material placed on a flattened slope at the shoreline to protect the shore from erosion by wave action.

RILL AND GULLY FLOW: The concentrated, channelized flow of water over the soil surface during a rainfall event.

SAND: Coarse-grained soils with a particle diameter of between 0.18 and 0.003 inch.

SCOURING: A cause of failure of shore protection structures where waves remove material at the base or toe of the structure.

SEAWALL: A structure of wood, stone, concrete, or steel erected along and parallel to a portion of a shoreline primarily to prevent erosion and other damage from wave action. Also called a bulkhead.

SHEAR STRENGTH: The ability of soil particles to resist stress forces which tend to cause adjacent particles to slide past each other.

SHEAR STRESS: The tendency of adjacent soil particles, when under stress, to slide past each other. When shear stress exceeds shear strength, the slope becomes unstable.

SHEETWASH: The unconfined flow of water over the soil surface during a rainfall event.

SHORELINE: The intersection of a water body with a shore or beach.

SILT: Fine-grained soils with a particle diameter of between 0.003 and 0.00015 inch.

SLIDING: A type of slope failure where material moves along a single slide plane.

SLOPE STABILITY ANALYSIS: A method of evaluating existing slope stability and for predicting bluff slope failure by utilizing geotechnical engineering techniques to quantify and evaluate those stress and strength factors that affect the bluff slopes.

SLUMPING: A type of rapid slope failure where a fairly large soil mass slides on a curved surface, usually rotating so that the top of the slump block is tilted back and toward the slope.

SOIL FLOW: A type of slope failure where the soil becomes saturated with water and the soil mass actually liquifies and moves like a fluid. Flows may be caused by surface water runoff, groundwater seepage, and the melting of intergranular ice.

SOLIFLUCTION: Soil flow resulting from the freeze and thaw of water which saturates the soil.

STABLE BLUFF SLOPE: The slope of a bluff face which, based on the physical characteristics of the soils, would not likely be affected by major types of slope failure. A stable bluff slope of one on two and one-half was identified for the City of St. Francis Lake Michigan bluff slopes.

STRUCTURAL EROSION RISK DISTANCE: The distance from the existing bluff which is expected to be affected by regrading of the bluff to a stable slope (the net stable slope distance). This distance applies to those shoreline areas which are currently stabilized, or which are protected, or planned to be protected, by proper shore protection structures.

STRUCTURAL SETBACK OVERLAY DISTRICT DISTANCE: For Lake Michigan shoreland areas which are currently stabilized or which are, or would be, protected by properly designed, constructed, and maintained shore protection structures, the distance from the existing bluff edge which would be lost by regrading of the bluff slope as needed to achieve a stable slope. The structural setback distance also includes a minimum facility setback distance.

STRUCTURAL SHORE PROTECTION MEASURES: Structures which are intended to reduce shoreline erosion and bluff recession by providing an artificial protective barrier against direct wave and ice attacks on the beach and bluff toe, by increasing the extent of the beach available to absorb wave energy before the water reaches the bluff, by dissipating wave energy, and/or by stabilizing the bluff slope. Shore protection structures include bulkheads or seawalls, revetments, groins, breakwaters, and slope stabilization measures.

UNDERCUTTING: A cause of failure of shore protection structures where the waves undercut the structure, removing material beneath the foundation.

WALE: Horizontal beam on a bulkhead used to laterally transfer loads against the structure and hold it in a straight alignment.

WAVE REFRACTION: The bending of waves near the shoreline due to variations in the water depth.

WEEP HOLES: Outlet in a bulkhead which prevents hydrostatic pressure buildup and frost heave.

Appendix B

RECOMMENDED AMENDMENTS TO THE CITY OF ST. FRANCIS ZONING ORDINANCE TO INCORPORATE SPECIAL REGULATIONS FOR EROSION RISK SETBACK DISTANCES ALONG THE LAKE MICHIGAN SHORELINE

1. Repeal and re-create Section 239.02 to read as follows:

239.02 DISTRICTS:
(1) For the purposes of this ordinance, the City of St. Francis, Wisconsin, is hereby divided into 10 basic districts and two overlay districts, as follows:

239.02 DISTRICTS:
Residence District R-1
Residence District R-2
Residence District R-3
Residence District R-4
Residence District R-5
Institutional Use District Iu
Business District B-1
Business District B-2
Industrial District M-1
Industrial District M-2
Structural Setback Overlay District SSO
Nonstructural Setback Overlay District NSO

(2) The boundaries of the aforesaid districts, except for the structural and nonstructural setback overlay districts, are hereby established as shown on the map entitled "District Zoning Map, St. Francis, Wisconsin," dated___________, 19___, which map accompanies and is made a part of this ordinance. All notations and references shown on the District Zoning Map are as much a part of this ordinance as though specifically described herein.

(a) The district boundaries are either streets or alleys, unless otherwise shown, and where the designation on the District Zoning Map indicates that the various districts are approximately bounded by a street or alley line, such street or alley line shall be construed to be the district boundary line.

(b) Where the district boundaries are not otherwise indicated and where the property has been or may hereafter be divided into blocks and lots, the district boundaries shall be construed to be lot lines, and where the designations on the District Zoning Map are approximately bounded by lot lines, said lot lines shall be construed to be the boundary of the district.

(c) In unsubdivided property, the district boundary lines shown on the District Zoning Map shall be determined by the use of the scale shown on the map.

(d) The boundaries of the SSO Structural Setback Overlay District shall be determined through the use of the following equation establishing a setback distance from the existing Lake Michigan bluff edge:

[SSO Structural Setback Overlay District Distance = Horizontal distance required to achieve one on two and one-half stable bluff slope + Minimum facility setback distance]

(e) The boundaries of the NSO Nonstructural Setback Overlay District shall be determined through the use of the following equation establishing a setback distance from the existing Lake Michigan bluff edge:

[NSO Nonstructural Setback Overlay District Distance = Horizontal distance required to achieve a one on two and and one-half stable bluff slope + (Average annual bluff recession rate x 50 years) + Minimum facility setback distance]

2. Add to Section 239.04:
Add the following definitions, in the appropriate alphabetical order, to Section 239.04:

239.04 DEFINITIONS:
Bluff: The often steeply sloped land area located to the landward side of Lake Michigan beach.

Bluff Recession Rate: The rate at which the bluff recedes because of erosion by the waters of Lake Michigan and because of unstable slope conditions.

Minimum Facility Setback Distance: A component of the structural and nonstructural setback overlay district distances which represents a setback distance measured from the regraded stable sloped bluff edge which provides a safety factor against possible failure of shore protection structures or the occurrence of higher than expected bluff recession rates, provides a buffer area which helps protect the regraded bluff edge from excessive surface runoff and from the potential bluff slope stresses resulting from the additional weight of buildings being placed close to the bluff edge, and provides an area which may be effectively utilized for surface water and subsurface water drainage and control.

Net Stable Slope Distance: The horizontal distance that the top of the bluff would need to recede, or be regraded, to form a stable bluff slope, which would not likely be affected by major slope failure processes such as slumping or sliding. The stable slope distance is one component of the structural and nonstructural setback overlay district distances.

Nonstructural Setback Overlay District Distance: For Lake Michigan shoreland areas which are actively eroding and not to be protected by properly designed, constructed, and maintained structural shore protection measures, the distance from the existing bluff edge which is expected to be affected by shoreline erosion and bluff recession over a 50-year period, and by regrading of the bluff slope as needed to achieve a stable slope. The non-structural setback distance also includes a minimum facility setback distance.

Structural Setback Overlay District Distance: For Lake Michigan shoreland areas which have stabilized shorelines or which are to be protected by properly designed, constructed, and maintained structural shore protection measures, the distance from the existing bluff edge which would be lost by regrading the bluff slope as needed to achieve a stable slope. The structural setback distance also includes a minimum facility setback distance.

Structural Shore Protection Measures: Structures which are intended to reduce shoreline erosion and bluff recession by providing an artificial protective barrier against direct wave and ice attacks on the beach and bluff toe, by increasing the extent of the beach available to absorb wave energy before the water reaches the bluff, by dissipating wave energy, and/or by stabilizing the bluff slope. Structural shore protection measures include bulkheads, revetments, groins, breakwaters, slope stabilization measures, and surface water and groundwater drainage facilities.

3. Add to Section 239.05:
Add the following provisions in continuation of the existing provisions to Section 239.05:

239.05 GENERAL PROVISIONS:
(20) Shoreland Uses:
(a) Principal Uses: The following shoreland uses are permitted within the structural and nonstructural setback overlay districts: surface water and groundwater drainage and control facilities, open space uses, storage of portable equipment and supplies, accessory buildings such as storage sheds, and minor facilities such as driveways, sidewalks, patios, and fences.

(b) Conditional Uses: The following may be conditional shoreland uses within the structural and nonstructural setback overlay districts, subject to the approval of the City Plan Commission:

(1) Land disturbance and earth movements not prohibited in Section 239.05(15), such as grading, topsoil removal, excavation, and soil and water conservation structures, provided that such uses are so regulated as to prevent erosion and sedimentation and to not increase the risk of bluff slope failure.

(2) Tree cutting and shrubbery clearing provided that such cutting and clearing shall be so regulated as to prevent erosion and sedimentation, preserve and improve scenic qualities, and not increase the risk of bluff slope failure. The Zoning Administrator shall request a review of such tree cutting and shrubbery clearing in excess of one (1) acre by the State Department of Natural Resources and await its recommendations before taking final action but not to exceed sixty (60) days.

(3) Structural shore protection measures for the Lake Michigan shoreline such as revetments, bulkheads, groins, and breakwaters. All such structures shall meet the criteria set forth in Table 11 in Chapter III of SEWRPC Community Assistance Planning Report No. 110, A Lake Michigan Coastal Erosion and Related Land Use Management Study for the City of St. Francis, Wisconsin.

(c) Prohibited Uses: The following are prohibited shoreland uses within the structural and nonstructural setback overlay districts: new, permanent residential, institutional, commercial, industrial, and recreational buildings and facilities; and streets.

4. Repeal and re-create the following section numbers:

	Old Numbers	Revised Numbers
Board of Appeals	239.16	239.18
Changes and Amendments	239.17	239.19
Administration, Enforcement, and Penalties	239.18	239.20
Legal Status	239.19	239.21

5. Create Section 239.16 to read as follows:

239.16 STRUCTURAL SETBACK OVERLAY DISTRICT SSO
The SSO Structural Setback Overlay District is intended to be used to protect people and property from shore erosion damage in Lake Michigan shoreland areas protected by properly designed, constructed, and maintained shore protection structures, and in areas with stabilized shorelines not protected by structures. All new development within these shoreland areas shall be adequately protected by a stabilized shoreline or, where necessary, by properly designed, constructed, and maintained structural shore protection measures. Such structural shore protection measures shall meet the criteria set forth in Table 11 in Chapter III of SEWRPC Community Assistance Planning Report No. 110, A Lake Michigan Coastal Erosion and Related Land Use Management Study for the City of St. Francis, Wisconsin.

In delineating the SSO district, the required recession or regrading of the bluff needed to form a stable slope, plus a minimum facility setback distance, shall be computed. The stable slope provides protection against further major bluff recession, as long as the structural shore protection measures are effective. This stable slope distance is measured from the existing bluff edge. The distance required to achieve a one on two and one-half stable bluff slope is set forth in Table 13 in Chapter III of SEWRPC Community Assistance Planning Report No. 110, A Lake Michigan Coastal Erosion and Related Land Use Management Study for the City of St. Francis, Wisconsin, and shall be used to determine the stable slope distance.

The minimum facility setback distance is then measured from the edge of the regraded bluff needed to form a stable slope. The minimum facility setback distance provides a safety factor against possible failure of the structural shore protection measures during extreme storm events or other natural occurrences, and provides a buffer area which helps protect the regraded bluff edge from excessive surface water runoff and from the potential bluff instability which could be caused by the additional weight of buildings being placed close to the bluff edge. In addition, the minimum facility setback distance provides an area which may be effectively utilized to facilitate surface water and subsurface water drainage and control. Minimum facility setback distances measured from the edge of the net stable slope distance shall be 100 feet for all permanent buildings and facilities.

The calculated structural setback overlay district distance may be modified upon submittal by an applicant or property owner of acceptable engineering analyses which indicate that the required distance for a stable slope is different from that defined in SEWRPC Community Assistance Planning Report No. 110, or that the height of the bluff is different from the assumed height. The City Plan Commission may also modify the required minimum facility setback distance if an applicant or property owner submits acceptable engineering and geotechnical analyses which indicate that application of a minimum facility setback distance of less than 100 feet would provide an adequate safety factor and not increase the risk of bluff slope failure.

6. Create Section 239.17 to read as follows:

239.17 NONSTRUCTURAL SETBACK OVERLAY DISTRICT NSO
The NSO Nonstructural Setback Overlay District is intended to be used to protect people and property from shore erosion damage in Lake Michigan shoreland areas which are actively eroding and which are not protected by properly designed, constructed, and maintained shore protection structures.

In delineating the NSO district, the expected bluff recession over a 50-year period, plus the required recession, or regrading of the bluff needed to form a stable slope, plus a minimum facility setback distance from the regraded bluff edge shall be computed. The NSO district thus includes those Lake Michigan shoreline areas which, based on historical bluff recession rates, are expected to be lost because of bluff recession and the formation of a stable slope over a 50-year period, plus a minimum facility setback distance. The distance required to achieve a one on two and one-half stable bluff slope is set forth in Table 13 in Chapter III of SEWRPC Community Assistance Planning Report No. 110, A Lake Michigan Coastal Erosion and Related Land Use Management Study for the City of St. Francis, Wisconsin, and shall be used to determine the stable slope distance.

Minimum facility setback distances measured from the edge of the net stable slope distance shall be as follows:

a. 200 feet for all permanent buildings and facilities except public utilities and outdoor recreational facilities.

b. 100 feet for public utilities and outdoor recreational facilities.

The calculated nonstructural setback overlay district distance may be modified upon submittal by an applicant or property owner of acceptable engineering analyses which indicate that the actual bluff recession rate is different from that set forth in SEWRPC Community Assistance Planning Report No. 110, that the required distance for a stable slope is different, or that the height of the bluff is different from the height presented in the report. The City Plan Commission may also modify the required minimum facility setback distance if an applicant or property owner submits acceptable engineering and geotechnical analyses which indicate that application of a minimum facility setback distance of less than as specified above would provide an adequate safety factor and not increase the rate of bluff recession.

7. Add to Section 239.21:

239.21 LEGAL STATUS:
(5) Nonliability: The nonstructural setback overlay district distance provisions for the Lake Michigan shoreland are considered the minimum reasonable requirements necessary to reduce bluff recession damages to buildings and facilities for an anticipated 50-year hazard period. These requirements are based upon engineering, geological, and other scientific studies and principles. Higher rates of erosion may occur. Erosion rates may be increased by natural causes such as major storms or high lake levels or by man-made causes such as construction activities. Similarly, compliance with the structural setback overlay district distances set forth in this Ordinance is assumed to provide reasonable protection from further bluff recession if the structural shore protection measures are properly designed, constructed, and maintained. However, even proper structural protection measures meeting all of the required criteria may fail during major storm events or other natural occurrences.

These regulations do not guarantee or warrant that development in compliance with its terms will be protected from all erosion damage. Reliance on these regulations shall not create liability on the part of the City of St. Francis, or employees, for any erosion damages that may occur as a result of reliance upon, and conformance with, this Ordinance.

Appendix C

INDEX OF MAPS SHOWING CITY OF ST. FRANCIS LAKE MICHIGAN NONSTRUCTURAL EROSION RISK AREAS AND SETBACK AREAS

Source: SEWRPC.

MAP C-1

Map C-2

MAP C-3

Appendix D

INDEX OF MAPS SHOWING CITY OF ST. FRANCIS LAKE MICHIGAN STRUCTURAL EROSION RISK AREAS AND SETBACK AREAS

Source: SEWRPC.

MAP D-1

MAP D-2